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526.
(Vol. XXVI.—May, 1892.)

ON THE LOSS OF HEAD RESULTING FROM THE PASSAGE OF WATER THROUGH A 24-INCH

ERRATA.

In *Transactions* for April, page 416, line 11, for *built* read *ballasted.* Line 25, same page, for *removal* read *renewal.* Page 419, title to first column of table, for *final* read *fiscal.* Page 420, line 24, for *semi-fine* read *semi-fire.* Page 421, line 27, for *transaction* read *transactions.* Page 425, line 29, for *sand* read *soil.* Line 37, same page, for *repaved* read *repoured.*

On page 403, add after the word "constructed," in the 9th line, the words "in Cincinnati," so that the sentence shall read, "constructed in Cincinnati," etc.

the merit of being both sensitive and accurate, and which may also be applied in other similar investigations, such as the determination of the loss of head due to the passage of a certain quantity of water through a partially opened stop valve.

In principle, the gauge consists of two vertical glass tubes, connected together at the bottom and partially filled with mercury, while the upper ends of these tubes are connected with the water main by means of suitable cocks and piping. On the admission of the water into the two tubes, the mercury will be depressed in one and raised in the other until equilibrium is established, whereupon the difference in the

heights of the two mercury columns is to be read off on a suitable scale, whose divisions correspond to known pressures of water, as determined by careful experiment beforehand. In practice, however, it is necessary to exercise the utmost care to expel all of the air in the tubes above the mercury, except when compressed air alone is applied in both, and for this purpose a little complication of the apparatus seems unavoidable.

The actual construction of the gauge is clearly shown in Plate XXXVIII, where it is seen standing upon the table used for operations in the field. The latter consists simply of a short piece of plank, to which three equidistant tee branches are attached by means of rods, so as to form collars, which may slide upon three long iron stakes driven into the ground, and may then be fixed to these stakes by set screws after the plank is approximately level at the desired height. The gauge is fastened to the plank table by three screws in the tripod which forms its base, and is then brought into a vertical position by means of the leveling screws and spirit levels. To insure absolutely equal initial water pressure upon the two columns of mercury, the two tubes are prolonged upward into a small reservoir or cistern partly filled with water; and if the mercury does not stand at the same height in both tubes, it is evident that some air is contained in one of them, which must be expelled by a judicious manipulation of the inlet cocks. To prevent the accidental loss of mercury in this operation, a hood is fitted over the small cistern mentioned, and is held in place by a set screw. After the gauge has thus been adjusted, the two upper cocks are closed and the full pressure from the main admitted into each tube from the inlet cocks. From time to time the pressure may also be shut off, and the above-described test or adjustment repeated. The scale is mounted between the two tubes, and is provided with two slides carrying arms which extend over both glasses, so that one may be used on one glass and the other one on the other glass. In case of considerable fluctuation, an observer is needed for each tube, and a good check on the observation will be gained if the two observers change places after each reading, and repeat.

An application of this instrument was made on May 31st, 1891, by John Thomson, M. Am. Soc. C. E., and the writer, to the 24-inch inlet pipe of the distributing reservoir of the Rochester, N. Y., Water Works, for the purpose of measuring the losses of head in the passage of the water through a partly opened 24-inch stop valve. This valve

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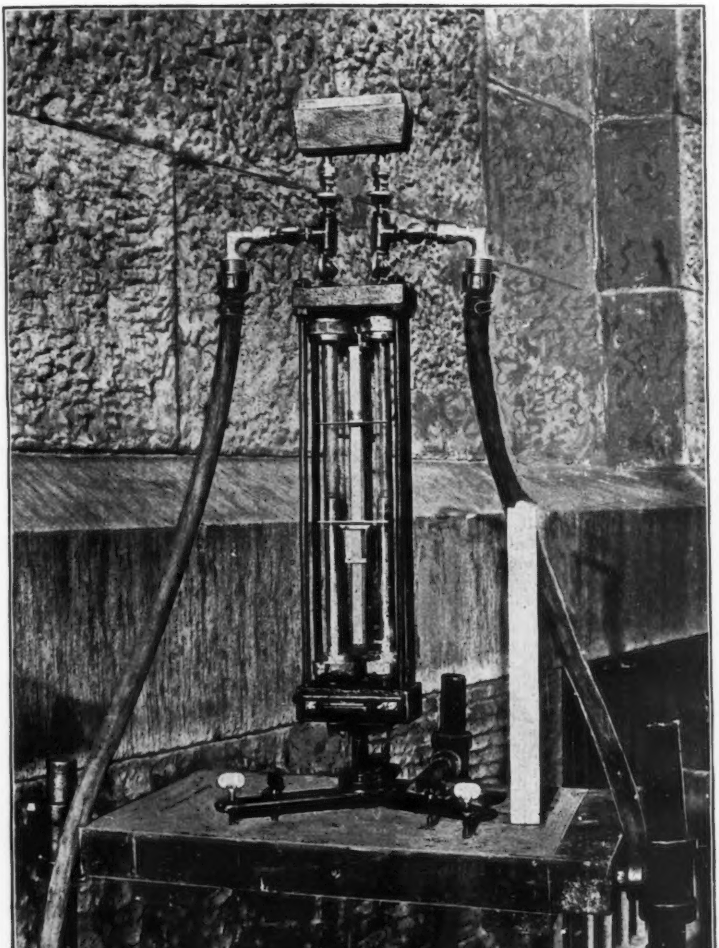

Plan of Mercury-Pressure-Difference Gauge.

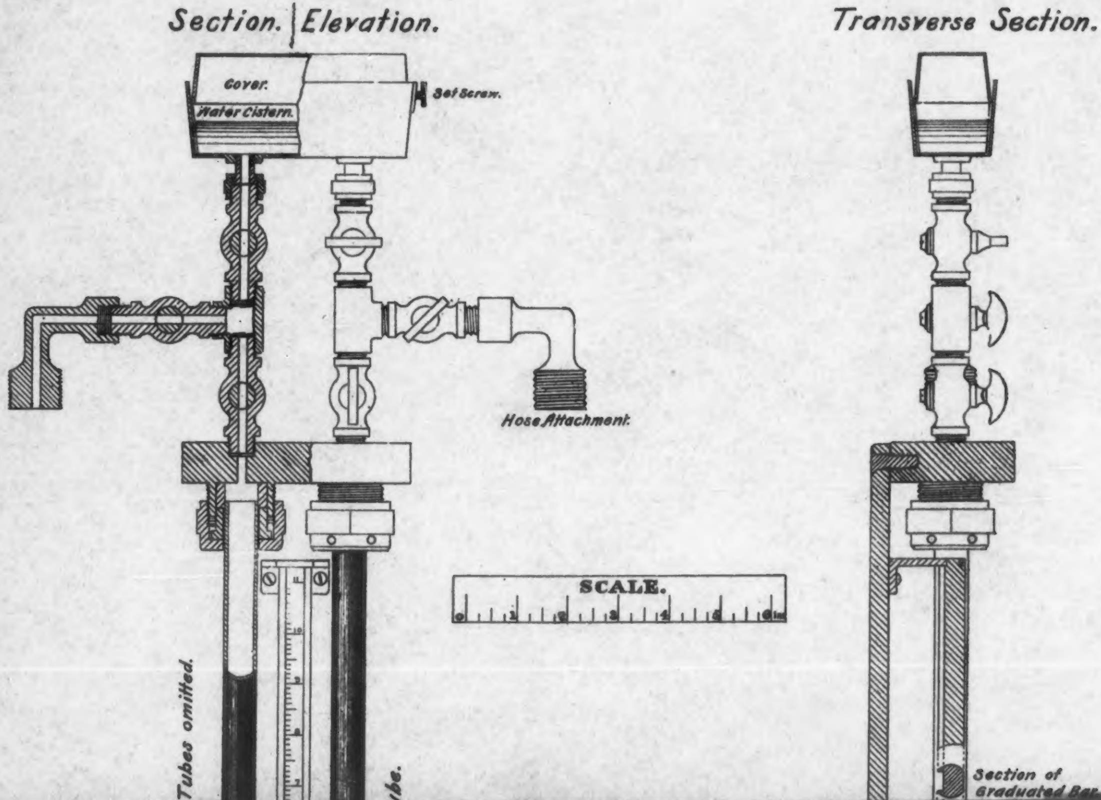

PLATE XXXVI
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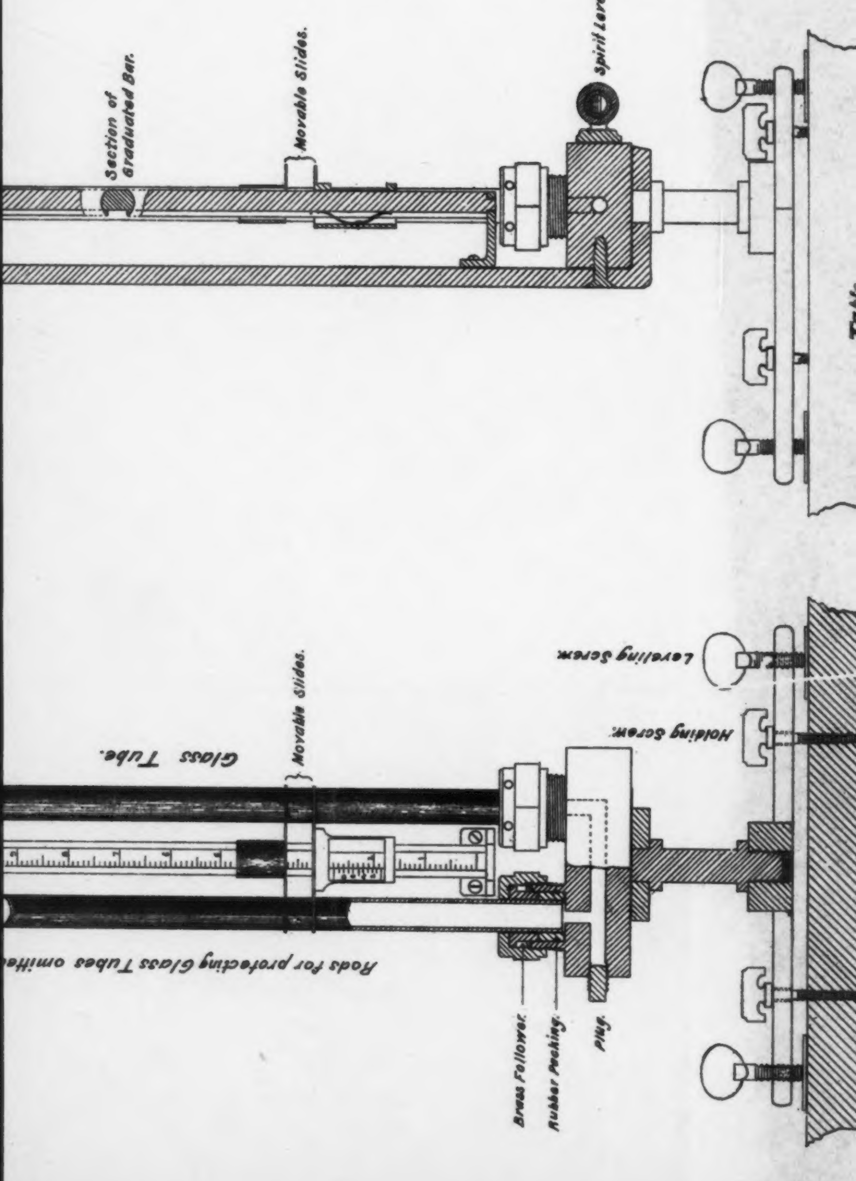

TE XXXVIII.
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ON LOSS OF HEAD
NCH STOP VALVE.

was made by the Ludlow Valve Manufacturing Co., of Troy, N. Y., in 1874, and has two parallel and circular cast iron disks, whose faces are about 6 inches apart and 26.5 inches in diameter. The brass rings forming the two valve seats are each 24.0625 inches in internal diameter, as stated by the manufacturers, so that, as the disks are raised up, a lune-shaped orifice (governed by the two diameters mentioned) is presented for the discharge of the water. The disks are moved by means of a screw stem having three threads per inch of length, and they overlap the valve seat on the bottom about 1 inch, whereby about three turns of the stem are required to bring the valves to a full bearing after the area of the lune has been reduced to zero in closing; and, conversely, the same number of turns is necessary in opening the valve before the lower edges of the disks coincide with the valve seats and begin to make an appreciable width of orifice of discharge. A check on the amount of overlap in the gate valve under consideration was secured at the time of the experiment by fully closing the valve, and then noting the number of turns of the screw stem required in opening before any appreciable discharge occurred, as determined by a waterphone; and by this method, also, the overlap was found to be about 1 inch, or three turns of the stem.

The area of the lune-shaped orifice of discharge for different positions of the disks, or heights of opening, was computed from the above values of the diameters as given by the manufacturers, viz.: $d_1 = 24.062$ inches, and $d_2 = 26.5$ inches, and the results are submitted in the following table, the headings of which are self-explanatory:

TABLE No. 1—SHOWING AREAS OF LUNE-SHAPED ORIFICES IN A 24-INCH LUDLOW STOP VALVE FOR DIFFERENT HEIGHTS OF OPENING.

Number of turns of stem required to raise disks. (N)	Ratio of diameter (d_1) of full orifice to height of opening (nd_1). $n = \frac{nd_1}{d_1}$	Ratio of full orifice (A) to lune-shaped orifice (F). $m = \left(\frac{F}{A}\right)$	Area of lune shaped orifice of discharge (F) in square feet.
3	0.0	0.0000	0.00000
10.2	0.1	0.1061	0.33524
17.4	0.2	0.2328	0.73537
24.6	0.3	0.3590	1.13401
31.8	0.4	0.4815	1.52078
39	0.5	0.5984	1.89002
46.2	0.6	0.7077	2.23527
53.4	0.7	0.8070	2.54873
60.6	0.8	0.8933	2.82113
67.8	0.9	0.9614	3.03711
75	1.0	1.0000	3.15809

By plotting the values of (m) or (F) as ordinates to the corresponding values of (n) or (N) as abscissas, a diagram can easily be constructed from which the values of the ratio (m) or the area of the lune-shaped orifice (F), for any other values of (n) or (N), may quickly be found by inspection. Such a diagram is shown on Plate XXXIX.

It may also be of interest to note the difference between the above values of the ratio (m) and those found by Weisbach in his experiments with small pipes and valves, as given in the following table:

For: $n =$	0	⅛	¼	⅜	½	⅝	¾	⅞	1.0
Above Table gives: $m =$	0.000	0.138	0.296	0.451	0.598	0.733	0.853	0.948	1.000
Weisbach " $m =$	0.000	0.159	0.315	0.466	0.609	0.740	0.856	0.948	1.000

The relation between (n) and (m) cannot be expressed analytically in convenient form, but if an approximation is deemed sufficient for any particular purpose, the following expressions, which were found after a number of trials, may be of service:

(1).....$m = 1.17n - 0.17n^6$ for the above-named 24-inch valve; and

(2).....$m = 1.26n - 0.26n^4$ for Weisbach's valve.

The valve under consideration is set on one arm of a Y-branch in the pipe conduit, and the taps for the hose attachments with the pressure-difference gauge were inserted with a tapping machine, so as to stand truly at right angles to the surface of the 24-inch cast iron pipes and without projecting into the interior thereof. The relative positions of the valve, taps, etc., is fully shown on Plate XL.

The water supply was derived by gravity from the storage reservoir through a continuous line of cast iron 24-inch pipe, about 46 219 feet in length to the valve in question, and was discharged from said valve into the distributing reservoir through about 648 feet of similar pipe, the difference in level between the two reservoirs being 112.89 feet at the time of the experiments. With the valve wide open, the pipe would accordingly have a total length (l) of about 46 867 feet, a total head (h) of 112.89 feet, and a nominal diameter (d) of 2.0 feet. The actual mean diameter of the conduit is probably a little greater than 24 inches, since a recent measurement of a few remaining pieces of the lightest class of the original lot of pipes gave a diameter of 24.84 inches, while in the heaviest class the diameter was 23.97 inches, thus indicating that the

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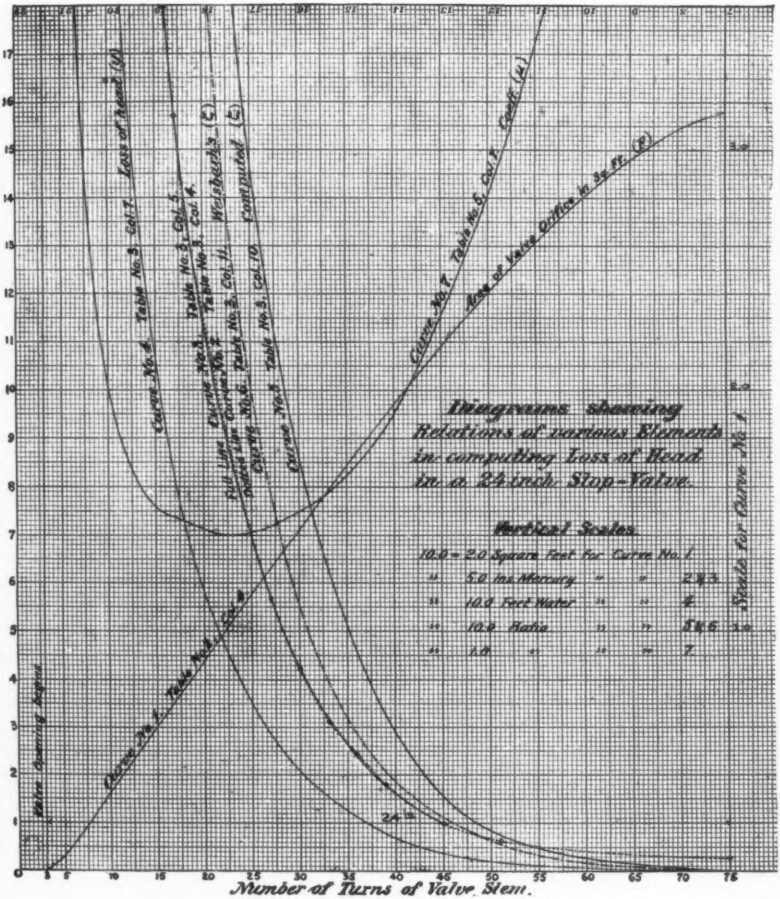

PLATE XL.
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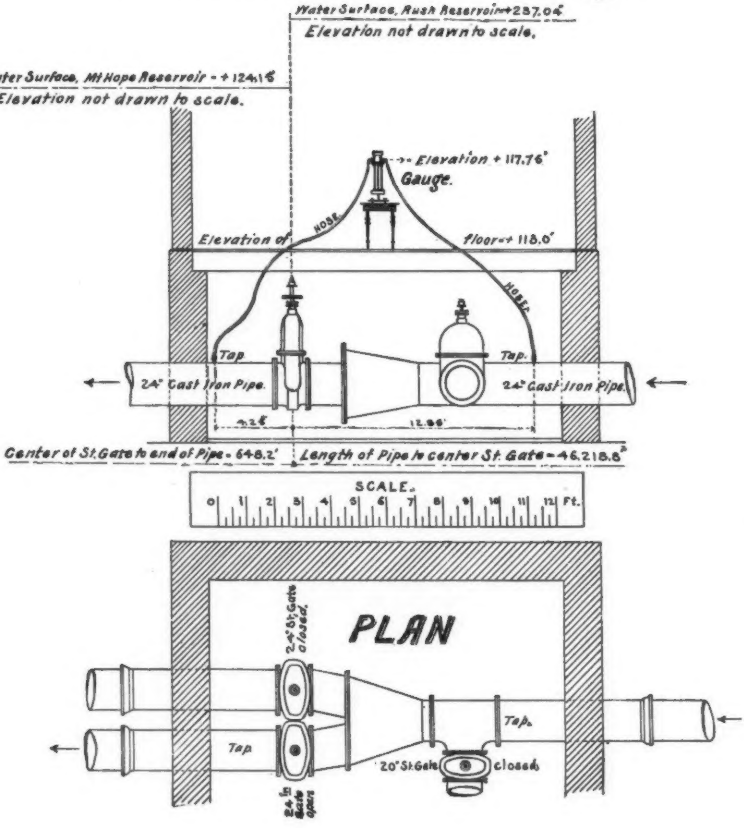
Diagram showing Position of 24 inch Valve and Difference Gauge.



specified variations in shell thickness for the different classes of 24-inch pipe used in the construction of the conduit, were, in some instances at least, effected by increasing the interior diameter above the 24 inches required for the thickest pipe. It may also be remarked that none of the heaviest class of such pipe was used between the aforesaid reservoirs. Assuming that the mean diameter of the conduit is exactly 24 inches, it was found from other recent gaugings that the discharge from said pipe may be computed approximately from the formulas:

$$(3) \ldots . v = 114.5 \sqrt{rs} = 57.25 \sqrt{\frac{d.h}{l}} = 0.37399 \sqrt{h}; \text{ and}$$

$$(4) \ldots . Q = 44.964 \sqrt{d^5 s} = 44.964 \sqrt{\frac{d^5 h}{l}} = 1.17491 \sqrt{h},$$

where (v) denotes the mean velocity in feet per second, and (Q) the discharge in cubic feet per second; also where the last expressions for (v) and (Q) result from the substitution of the above numerical values for (d) and (l). Both of these expressions will be useful for finding the velocity or discharge when the valve is partially closed, in which case it will only be necessary to substitute for (h) the difference between the total fall of 112.89 feet above mentioned and the observed loss of head in passing through the valve.

Previous to making the experiments, the mercury gauge had been carefully calibrated in the office at a temperature of about 65 degrees Fahr., the water used at the time being about 50 degrees Fahr. The results thus obtained were as follows:

Measured Head of Water in Feet.	Observed Difference in height of Mercury Columns in Inches.	Deduced Equivalent of 1 Inch of Mercury in Feet of Water.
1.0	0.955	1.0471
2.0	1.905	1.0499
3.0	2.870	1.0453
4.0	3.800	1.0526
5.0	4.765	1.0493
		Average = 1.0488

The scale was graduated into inches and tenths, and with the vernier on the sliding arm, readings could be taken directly to hundredths of an inch, while the thousandths were estimated. As any slight error of observation is relatively greater for the head of 1 foot than for the greater heads, the first observation may be rejected, whereupon the average of the remaining four observations will give a head of 1.0493

feet of water to balance a head of 1 inch of mercury in the gauge, and this factor has accordingly been adopted in the reduction of the following observations. It may also be remarked in this connection that the glass tubes were not quite of equal bore, one being a little over and the other a little under three-eighths of an inch in diameter at each end.

After the gauge had been connected to the 24-inch pipe on each side of the valve, and properly adjusted as above described, the following observations were made: (See Table No. 2.)

It should be remarked that in attempting to test the adjustment of the gauge after the second observation, some of the mercury was blown out through carelessness, so that the experiment had to be continued with the remainder. A subsequent calibration of the gauge, however, showed no appreciable difference from the one obtained originally, and hence the above factor (1.0493) for reducing heads in inches of mercury to feet of water has been retained. The Crosby spring pressure gauge referred to in Table No. 2, is used for ascertaining the loss of head approximately, in comparison with the observed depth of water in the reservoir, and is connected with the conduit pipe independently from a tap located about 14 feet above the 24-inch valve. The records of this spring gauge are of interest here, only in so far as they show a noticeable lack of sensitiveness in the instrument for the purpose of such experiments.

TABLE No. 2.—GIVING RECORD OF OBSERVATIONS WITH PRESSURE-DIFFERENCE GAUGE FOR VARIOUS HEIGHTS OF OPENING OF 24-INCH VALVE.

No. of turns of valve stem in opening.		Lift of Valve Disks above Seat, as per Indicator (inches).	Reading of Crosby Spring Pressure Gauge (pounds).	Height of Mercury Column in Left Tube, as per Scale (inches).				Height of Mercury Column in Right Tube, as per Scale (inches).				Loss of head in inches of Mercury.
Total.	Estimated from valve seat.			Maximum.	Estimated Average.	Minimum.	Computed Average.	Minimum	Estimated Average.	Maximum.	Computed Average.	
16	13		7.50	1.100	—	0.400	0.750	9.280	—	10.180	9.730	8.980
17	14			1.600	—	0.960	1.280	8.780	—	9.490	9.135	7.855
18	16	5	6.75	0.650	0.360	0.050	0.353	6.860	7.240	7.580	7.227	6.874
21	18	6	6.00	1.440	1.040	0.820	1.100	6.040	6.395	6.650	6.362	5.262
27	24		5.00	2.410	2.170	2.050	2.210	4.850	5.100	5.220	5.057	2.847
30	27		5.00	2.650	2.570	2.400	2.540	4.520	4.655	4.780	4.652	2.112
33	30	10	5.00	2.960	2.800	2.650	2.803	4.230	4.370	4.500	4.367	1.564
36	33		4.75	3.095	2.990	2.840	2.975	4.093	4.195	4.290	4.193	1.218
39	36		4.75	3.230	3.115	2.985	3.110	3.850	4.000	4.175	4.008	0.898
45	42	14	4.50	3.340	3.310	3.225	3.292	3.720	3.790	3.850	3.787	0.495
51	48		4.25	—	3.383	—	3.385	—	3.700	—	3.700	0.315
75	72	24	4.00	—	3.465	—	3.465	—	3.600	—	3.600	0.135

Several hours were spent in making the observations recorded above, and much care was taken to obtain accurate results. The maximum and minimum heights in the two tubes were taken simultaneously by an observer at each tube, who adjusted one of the two slides to the level of the mercury and uttered a call when coincidence occurred. No reading of the scale was taken until at least two calls were pronounced simultaneously, and to verify the observation the observers changed places and repeated the calls. In every instance, also, several minutes were allowed to elapse after changing the position of the valve disks before making an observation, in order to allow a uniform flow to be established; and it may be remarked that any change of the disks was immediately followed by an alteration in the heights of the mercury columns, which appeared to remain constant until another change of the disks occurred.

As will be seen from the records, there was much oscillation of the mercury in the two tubes while the disks were raised only a few inches above the valve seat, and it will also be noticed that the amplitude of these oscillations gradually diminished as the opening became larger. After the disks had been fully raised, however, there was still a considerable oscillation even after a long interval of time, which may be attributed either to variations of barometric pressure at the two reservoirs, or to eddies in the water, or to both of these causes conjointly. The same oscillation was also observed, both previous and subsequent to these experiments, on applying the gauge to the same line of pipe at a locality about 6 miles distant from the distributing reservoir, and at a time when no change whatever was made in any valve or other fixture on the line. No regularity in these fluctuations could be detected, either in respect to time or magnitude, and hence the writer is inclined to ascribe them more to sudden variations in atmospheric pressure at the two basins of water 9 miles apart, than to eddies in the current flowing through the pipe.

It will be observed from Table No. 2 that even after the 24-inch valve had been fully opened, a loss of head of 0.135 inches of mercury was still indicated by the gauge. This loss is obviously due to the friction in a length of 17.10 feet of pipe and special casting, combined with changes both in direction and sectional area. To find the loss of head caused by the valve disks alone, this quantity should be deducted from the total losses of head in the last column of said table, and, as its magnitude will probably not undergo material change within the range of the experiments, it may be regarded as constant. Before making this de-

duction, however, it will be of interest to ascertain some notion of the law governing these losses of head, and for this purpose they have been plotted on Plate XXXIX as ordinates to the corresponding degree of opening of the valve, or number of turns of the stem, as abscissas. Through most of the points thus obtained it is easy to pass a continuous and apparently regular curve by bending a flexible steel or wooden rod, and, as is usual in all such cases, it will be assumed that this curve will represent the law more correctly than the actual observations. By this means a new series of values for the losses of head in inches of mercury will be obtained, from which the aforesaid deduction of 0.135 inch for friction, etc., can be made, whereupon the reduction into feet of water, as well as other operations, may follow. In Table No. 3 the figures given in the fourth column are the observed losses of head, as in Table No. 2; those in the fifth column are obtained from the said curve drawn to a large scale, and are designated as "corrected total losses of head"; those in the sixth column are obtained by subtracting 0.135 from the figures in the preceding column, as above mentioned, and represent the probable losses of head, expressed in inches of mercury, from the valve disks alone; while the seventh column gives the same expressed in feet of water, using the factor 1.0493 as already mentioned. The remaining columns are sufficiently characterized by their headings.

TABLE No. 3.—SHOWING LOSSES OF HEAD DUE TO VALVE, TOGETHER WITH COEFFICIENT FOR COMPUTING SUCH LOSS.

Number of Turns of Valve Stem in Opening.		Ratio of diam. of full orifice (d_1) to height of opening $n = \frac{nd_1}{d_1}$	Observed Total Loss of Head in Inches of Mercury.	Corrected Total Loss of Head in Inches of Mercury.	Corrected Loss of Head due to the Valve Disks alone.		Net fall in entire Pipe Line between Reservoirs ($H-y$) feet.	Mean Velocity in Pipe from Eq. 3. (v) feet per second.	Computed Coefficient. $\zeta = \frac{2gy}{v^2}$	Weisbach's Coefficient. $\zeta_1 = \frac{2gy_1}{v_1^2}$
Total.	Estimat'd from Valve Seat				Inches of Mercury.	Feet of Water (y)				
1	2	3	4	5	6	7	8	9	10	11
16	13	$\frac{13}{72}$	8.980	8.980	8.845	9.281	103.61	3.8068	41.205	43.00
17	14	$\frac{7}{36}$	7.855	7.855	7.720	8.100	104.79	3.8284	35.557	35.00
18	15	$\frac{5}{24}$	6.874	7.000	6.865	7.203	105.69	3.8448	31.350	28.00
21	18	$\frac{1}{4}$	5.262	5.190	5.055	5.304	107.59	3.8792	22.677	17.00
27	24	$\frac{1}{3}$	2.847	2.845	2.710	2.844	110.05	3.9233	11.888	7.92
30	27	$\frac{3}{8}$	2.112	2.115	1.980	2.078	110.81	3.9368	8.626	5.52
33	30	$\frac{5}{12}$	1.564	1.595	1.460	1.532	111.36	3.9466	6.328	3.97
36	33	$\frac{11}{24}$	1.218	1.195	1.060	1.112	111.78	3.9540	4.576	2.87
39	36	$\frac{1}{2}$	0.898	0.895	0.760	0.797	112.09	3.9595	3.271	2.06
45	42	$\frac{7}{12}$	0.495	0.495	0.360	0.378	112.51	3.9669	1.545	1.11
51	48	$\frac{2}{3}$	0.315	0.315	0.180	0.189	112.70	3.9703	0.771	0.57
75	72	1	0.135	0.135	0.000	0.000	112.89	3.9736	0.000	0.00

The numerical values of the loss of head due to the valve disks alone, as given in the seventh column of Table No. 3, may also be plotted as ordinates for the corresponding number of turns of the valve stem in the second column as abscissas, thus obtaining another curve similar to the one referred to in the foregoing paragraph. To avoid confusion in the diagram, this curve has been omitted from Plate XXXIX. It will, however, be of interest to ascertain the equation of this curve, and hence also an expression of the law governing the losses of head mentioned. For this purpose, we denote the degree of opening of the valve, as given by the number of effective turns of the stem in the second column of Table No. 3 by (x); the loss of head due to the disks alone, as per seventh column of said table by (y); the total fall in the conduit by $H = 112.89$; and the number of effective turns of the stem to fully raise the disks by $C = 72$. Since the loss of head (y) cannot under ordinary circumstances become greater than H, we have at once the first condition, that for $x = 0$, $y = H$; and as the loss of head (y) is inappreciable after the disks are fully raised, there follows the second condition, that for $x = C$, $y = 0$. To satisfy these conditions the equation must have the form $y = H + ax^m + bx^n + \ldots.$ After a number of trials the writer found that the expression:

$$(5) \ldots\ldots\ldots\ldots y = 112.89 + 9.98 \sqrt{x} - 84.00 \sqrt[5]{x}$$

gives values for (y) which correspond fairly well with those in the seventh column of Table 3. A somewhat closer correspondence can be obtained by using more complicated fractional exponents for the terms involving (x), with other coefficients; but as the use of such factors is very tedious, only the simplest form has been given.

It is customary with the authors of modern text-books on hydraulics to cite the results obtained by Weisbach in his experiments with valves of relatively small diameter; and in order to compare the foregoing figures with the latter, Weisbach's method of expressing the loss of head (y) in terms of the mean velocity (v) in the conduit may now be applied. To find this velocity, the values of $h = H - y$ in the eighth column of Table No. 3 are to be substituted in the above equation 3, viz., $v = 0\ 37399 \sqrt{h},$ whence the figures given in the ninth column of said table are obtained; and to express the relation between (y) and (v), we may place with Weisbach: $y = \zeta \frac{v^2}{2g}$, or $\zeta = \frac{2gy}{v^2}$. From Pierce's formula for the acceleration of gravity (g) we also have, for the locality of

our experiments, where the latitude is about 43 degrees with an elevation of about 630 feet above the sea, $2g = 64.339$; and from these elements the values of (ζ) given in the tenth column of Table No. 3 have been computed. The results found by Weisbach, however, are always tabulated for a series of ratios (n) of the diameter (d_1) of the full orifice to the height (nd_1) of the lune-shaped orifice, which is somewhat different from the ratios occurring in our experiments, as given in the third column of said Table; and in order to institute a proper comparison, it is necessary to obtain Weisbach's values (ζ_1) corresponding to the latter ratios. For this purpose the values of (ζ_1) have been plotted as ordinates to the corresponding values of (n) as abscissas; and since there is a fixed relation between the ratio (n) and the number (x) of effective turns of the valve stem, it was easy to obtain from the resulting diagram the value of (ζ_1) corresponding to other values of (n) or (x). For the particular values of (n) or (x) here considered, the values of Weisbach's coefficient (ζ_1) are given in the eleventh column of Table No. 3.

The comparison of our values of the coefficient (ζ) with those given by Weisbach's experiments, shows a fair agreement only in the first three entries of Table No. 3, where the height of the lune-shaped opening is less than one-fourth of the diameter of the pipe or valve. For the remaining cases the values of (ζ) and (ζ_1) differ greatly until the valve has been raised nearly three-fourths of the whole diameter, whereupon they begin to approach each other again.

Attempts were also made to express analytically the relation of the coefficient (ζ) to the ratio (n) of the diameter (d_1) of the full valve opening to the height (nd_1) of the lune-shaped opening, but without much success. Since $\zeta = 0$ for $n = 1$, and $\zeta = \infty$ for $n = 0$, it is obvious that such relation must have the general form of—

$$\zeta = a\left(\frac{1-n}{n}\right)^s + b\left(\frac{1-n}{n}\right)^t + \ldots\ldots = aZ^s + bZ^t + \ldots\ldots$$

where for brevity we may place $Z = \dfrac{1-n}{n}$. The most satisfactory of the various forms tried are—for the coefficient (ζ) derived from our experiments—

(6) .... $\zeta = Z^2\,(4.9354 + 0.0614\,Z^2) - Z\,(0.8284 + 0.8974\,Z^2)$,

and for the coefficients (ζ_1) from Weisbach's experiments—

(7) .... $\zeta_1 = Z^2\,(2.21129 + 0.01903\,Z^2) - Z\,(0.00648 + 0.16384\,Z^2)$,

or, the simpler form:

(8) .... $\zeta_1 = 0.1\sqrt{Z} + 1.98\,Z^2$.

To indicate how closely these equations correspond with the experimental results obtained by the writer and by Weisbach respectively, a series of computations from said equations have been carried out in the following Table No. 4. Similar agreements, but not exact ones throughout, were obtained with fractional exponents; and as the use of such expressions is too tedious, they were discarded in favor of the simpler expressions mentioned. The law governing the relation of (ζ) to (n) is probably quite complicated, as may be seen by substituting for (y) in the expression for (ζ), its value as given by equation 5, along with the value of (v) from equation 3.

TABLE No. 4.—SHOWING COMPARISON OF EXPERIMENTAL AND COMPUTED RESULTS FOR THE COEFFICIENT (ζ).

No. of Turns of valve stem in opening. Estimated from valve seat.	Ratio of Diameter of full orifice (d_1) to height of opening (nd_1) $n = \frac{nd_1}{d_1}$	Factor $Z = \frac{1-n}{n}$	Coefficient $\zeta = \frac{2gy}{v^2}$		Values of Coefficient (ζ) Computed from		
			Computed from present Experiments.	Given by Weisbach.	Eq. 6.	Eq. 7.	Eq. 8.
0	0	∞	....	....	∞	∞	∞
9	$\frac{1}{8}$	7	....	*97.80	75.649	97.80	97.28
13	$\frac{13}{72}$	$\frac{59}{13}$	41.205	43.00	40.057	....	......
14	$\frac{7}{36}$	$\frac{29}{7}$	35.557	35.00	35.554	30.17	34.19
15	$\frac{5}{24}$	$\frac{19}{5}$	31.350	28.00	31.679	....	......
18	$\frac{1}{4}$	3	22.677	*17.00	22.677	17.00	17.99
24	$\frac{1}{3}$	2	11.888	7.92	11.888	....	......
27	$\frac{3}{8}$	$\frac{5}{3}$	8.626	*5.52	8.815	5.53	5.50
30	$\frac{5}{12}$	$\frac{7}{5}$	6.328	3.97	6.287	3.95	4.00
33	$\frac{11}{24}$	$\frac{13}{11}$	4.576	2.89	4.553	....	......
36	$\frac{1}{2}$	1	3.271	*2.06	3.271	2.06	2.08
42	$\frac{7}{12}$	$\frac{5}{7}$	1.545	1.11	1.717	....	......
45	$\frac{5}{8}$	$\frac{3}{5}$	....	*0.81	1.094	0.76	0.79
48	$\frac{2}{3}$	$\frac{1}{2}$	0.771	0.57	0.711	....	......
54	$\frac{3}{4}$	$\frac{1}{3}$	....	*0.26	0.240	0.238	0.277
63	$\frac{7}{8}$	$\frac{1}{7}$	....	*0.07	0.019	0.044	0.077
72	1	0	....	....	0.000	0.00	0.000

It will be observed that the difference-gauge above described measures directly the loss of head due to the lune-shaped orifice formed by partially opening the 24-inch stop valve, and it has occurred to the writer that in cases where said loss is known the discharge might be computed directly if the coefficient of discharge for such an orifice were known. From the foregoing data it is easy to compute this coefficient for the present case, by regarding the opening as a submerged orifice discharging under the head (y), from Table No. 3, and the area (F), from Table No. 1, in which event we have the well-known expression—

$$Q = \mu F \sqrt{2gy}\,; \text{ or, } \mu = \frac{Q}{F\sqrt{2gy}}\,;$$

The figures marked with an * are given directly by Weisbach. The remaining figures in this column are derived by scale from plotted curve.

where (Q) denotes the discharge in cubic feet per second, (F) the area of the lune in square feet, (y) the head in feet, and (μ) the required coefficient. Let us also denote by (A) the area of the complete circle formed by fully raising the gate, which, in cases like the present, is the same as the sectional area of the 24-inch pipe, and by (H) the total fall between the two reservoirs, thus leaving the effective head or fall in the conduit or pipe $= h = H - y$, with the length $= l$. The discharge of the pipe may be then represented by $Q = cA\sqrt{h}$, as in equation 4; and by substituting this latter value of (Q) in the above equation for the coefficient (μ), and combining the several constants, we obtain

$$(9)\ldots\ldots\ldots\ldots \mu = 0.046625 \frac{A}{F}\sqrt{\frac{h}{y}} = \frac{0.14648}{F}\sqrt{\frac{h}{y}}.$$

As the values (y) and (h) are given in columns 7 and 8 of Table No. 3, for various degrees of valve opening, and the corresponding values of (F) are readily obtained either by interpolation in the fourth column of Table No. 1, or by scale from the curve of (F) on Plate XXXVIII, the values of (μ) may now be easily computed, and then plotted as ordinates in a diagram as before. The results of this computation are given in the following table:

Table No. 5.—Showing Values of Coefficient of Discharge when the Valve Opening is considered as a Submerged Orifice.

Number of Turns of valve stem in opening.		Ratio of Diameter of full orifice (d_1) to height of opening (nd_1) $n = \frac{nd_1}{d_1}$	Area of orifice (F). Square feet.	Loss of head due to valve disks alone (y). Feet.	Net fall in entire pipe line between reservoirs. $h = (H - y)$. Feet.	Computed coefficient of discharge through orifice (μ).
Total.	Estimated from valve seat.					
3	0	0	0.00000	112.890	0.00	∞*
16	13	$\frac{13}{72}$	0.65760	9.281	103.61	0.74424
17	14	$\frac{7}{36}$	0.71315	8.100	104.79	0.73876
18	15	$\frac{5}{24}$	0.768	7.203	105.69	0.73058
21	18	$\frac{1}{4}$	0.934	5.804	107.59	0.70633
27	24	$\frac{1}{3}$	1.266	2.844	110.05	0.71972
30	27	$\frac{3}{8}$	1.427	2.078	110.81	0.74957
33	30	$\frac{5}{12}$	1.584	1.532	111.36	0.78840
36	33	$\frac{11}{24}$	1.738	1.112	111.78	0.84499
39	36	$\frac{1}{2}$	1.890	0.797	112.09	0.91910
45	42	$\frac{7}{12}$	2.180	0.378	112.51	1.15920
51	48	$\frac{2}{3}$	2.446	0.189	112.70	1.46230
75	72	1	3.15809	0.000	112.89	∞

* At the limit of $n = 0$, we have from equation 9, $\mu = \infty$ or $\frac{0}{0}$, since $F = 0$. Doubtless the proper value is $\mu = \infty$, since the values of (μ) from equation 9 steadily increase as (n) decreases from $\frac{13}{72}$ toward 0. Thus, if we assume that equation 5 correctly represents the relation of (y) to the number of effective turns of opening, we will have for an opening of only four turns $y = 21.97$ feet, $h = 90.92$ feet, and $F = 0.16$ square feet, whence $\mu = 1.862$.

Plan showing Details of 24inch Valve in Gate House of Distributing Reservoir.

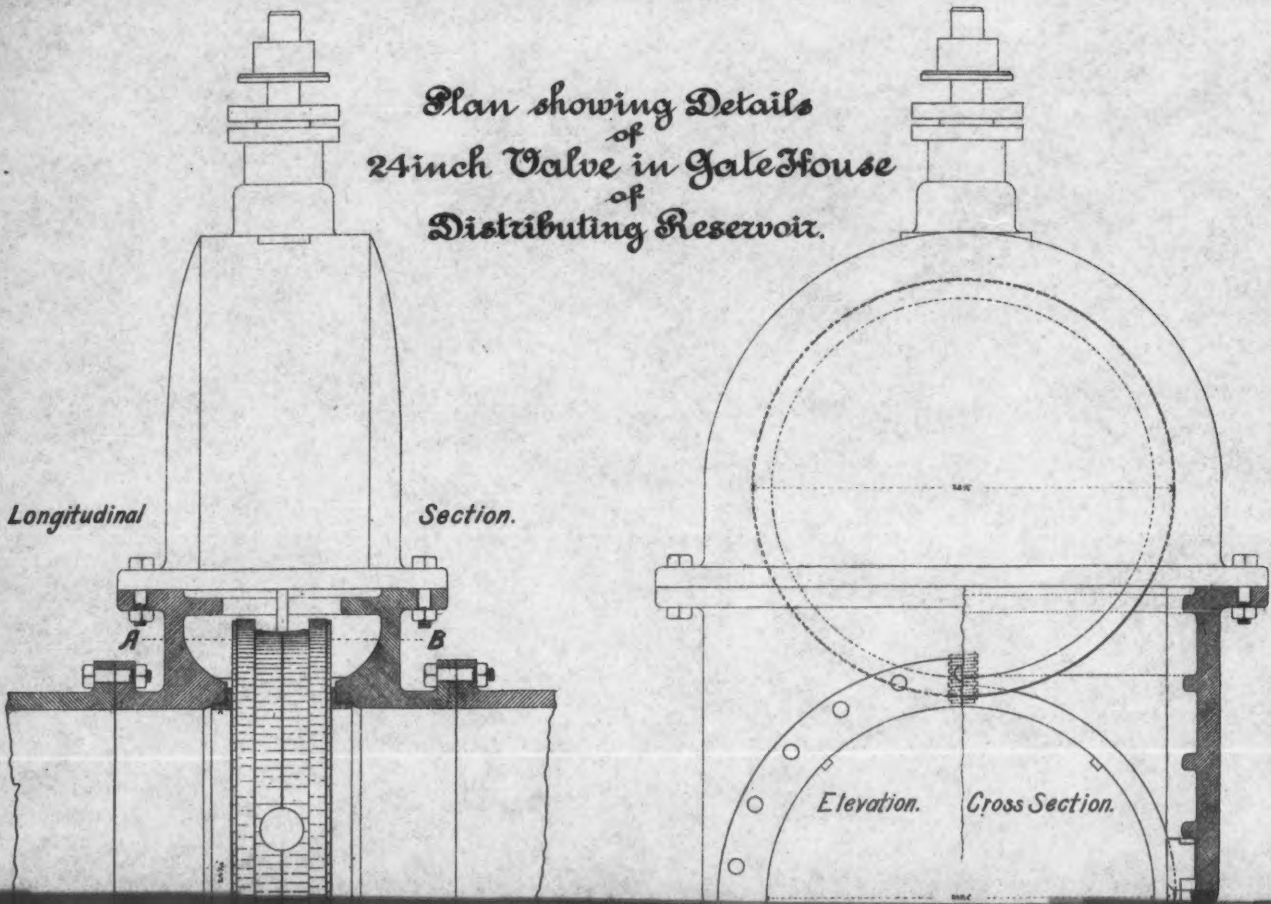


PLATE X
TRANS.AM.SOC.
VOL.XXVI.N
KUICHLING ON L
FROM 24 INCH

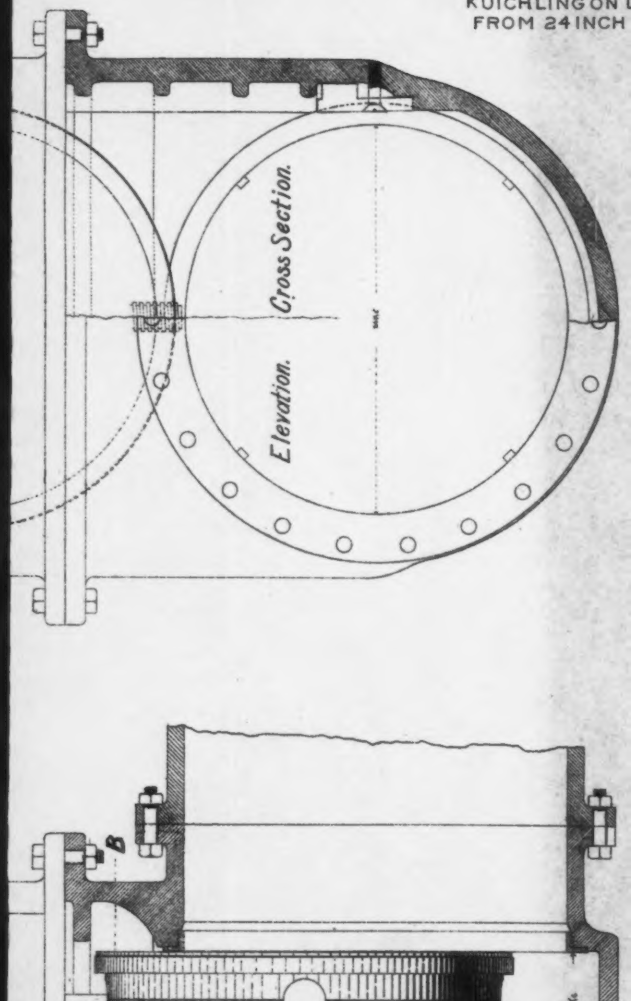
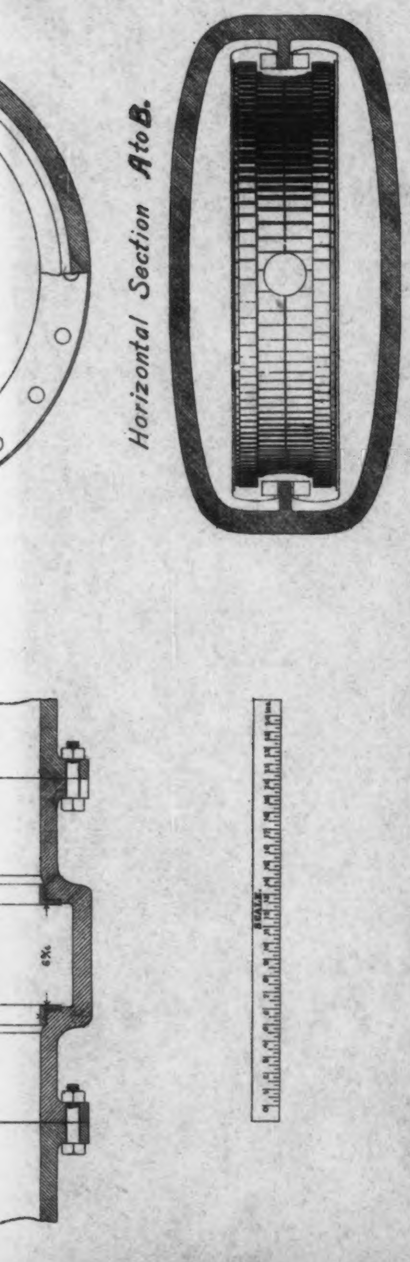


PLATE XLI.
...S.AM.SOC.CIV.ENG'RS.
VOL.XXVI.Nº526.
...LING ON LOSS OF HEAD
...M 24 INCH STOP VALVE.



From the figures in the last column of the foregoing table, the peculiar variation in the value of the coefficient (μ) is readily perceived, and can be made more apparent when these values are plotted as ordinates. While under ordinary circumstances where the discharge occurs from a higher into a lower reservoir with known difference of level, the use of the foregoing coefficient (μ) would not be desirable, yet there are often cases where it is difficult to determine correctly the value of (H), and in such cases the discharge through a throttled stop valve may be computed with fair accuracy by means of this coefficient when (F) and (y) are known. For any particular valve, the values of (F) can easily be computed, as in the present case, and by means of the mercurial difference-gauge above described, the values of (y) are readily obtained.

It is also of interest to note the irregularity in the curve for (μ) which appears in the diagram between the twelfth and nineteenth turn of the valve stem in opening, estimated from the top of the valve seat. This irregularity is obviously due to some slight errors in obtaining the loss of head with the pressure-difference gauge, owing to the considerable fluctuations of the mercury at these stages of valve opening. There is no reason why the said curve for (μ) should not be regular and continuous throughout; and the computation of the values of (μ) has accordingly proved to be not only an excellent check on the general correctness of the gauge observations, but also an indicator of the locality of possible errors in such observations.

DISCUSSION.

CLEMENS HERSCHEL, M. Am. Soc. C. E.—I did not intend to say anything on this paper, although it is one of those contributions to the *Transactions* of the Society which, to my mind, mark a distinct advance, even though it be in only a small branch of hydraulics, but still an advance, clearly and distinctly; a contribution of something new in engineering literature. It goes without saying that I am highly pleased, nay, delighted, with the paper. The treatment of the subject is a broad one; it is handled in a masterly, in an exhaustive, manner, and the results are such as may undoubtedly be used in future by others.

Comparison is made in the paper with results found by Weisbach; and I think that there is not, perhaps, sufficient emphasis given to the fact that whereas these experiments were made on a 2-foot valve, all of

Weisbach's experiments were made on small valves, say 1, 1½ and ¾ inch valves. This might be called an experiment out in the open, in the field, while Weisbach's were laboratory experiments. Under these circumstances the differences in the results of these experiments from Weisbach's, instead of surprising any one as differing from them, should excite surprise as to their being so nearly alike with them. One thing has pleased me very much—a person always likes to see the influence of his own work showing itself in course of time in other people's writings—viz., the use of what is called the difference gauge; and finally the rating, as we may call it, of this 2-foot valve for purposes of a water meter, by observing the differences of pressure on the two sides of the valve. Some members of the Society may remember that a couple of years ago I read a paper on what was called the Venturi water meter, one that I tested in a pipe of 9 feet diameter, also in a 1-foot pipe, and have since tested it in a 4-foot and a 1-inch pipe, which meter was based on this same idea of differences of pressure; that is, gauging the quantity of water flowing through a pipe and through this meter, by observing simply the differences of pressure at two points in the meter. That meter has been sufficiently tested now to prove it a valuable instrument. In it the coefficient is a constant, within ordinary limits, whereas in Mr. Kuichling's 2-foot valve, the coefficient naturally varies between wide limits as portrayed on his curve of these coefficients.

The subject taken as a whole is, of course, only a simple thing; although we can all appreciate, that to work it out and portray it in all its parts was the labor of a good many days, and had to be done with the greatest care and discretion in order to reach reliable results. I mean when I say it is a simple thing, that, after all, it is only the rating of a 2-foot valve; but little by little the whole science of hydraulics is built up of just such simple things. I can only regret that hydraulic engineers are not more frequently in position to make experiments of this sort. I believe it was Galileo who said that it was a matter of grief to him, that he could learn more about the course of the stars and planets than he could about the flow of water right on the earth which he inhabited. What he regretted is true to this day. In the case in hand Mr. Kuichling has been luckily so placed that he has been able to give us the action of water, as it flows through a 2-foot valve, and we have, in consequence, gained that much for the cause of hydraulics.

As to the subject of pulsations in flowing water, I remember very well when Mr. D. Farrand Henry was at work on the Detroit River, being in correspondence with him at the time; and from that day to this I have often noticed these pulsations, as anybody can, who will closely observe flowing water. I am not disposed to seek the cause; it is simply a fact; the cause is probably complex, but there it is. It is inherent in all flowing water, whether it goes over a weir, through a canal or river, or through a valve in a pipe. The fact is, there is no such

thing as uniformly flowing water, ordinarily speaking; there certainly is not, unless the water be issued at a very great velocity, and, even then, more delicate observation may reveal it. In ordinary velocities it plainly does not exist, and I have never seen any flowing water without pulsations. Of course, as to what constitutes a roughness, it may be said that the matter of roughness and smoothness is one of relative terms. If we take a canal 180 feet wide and 15 feet deep, and compare that with the roughness of a rubble wall on each side, the canal might be called a smooth channel, yet these pulsations exist in the thread of the current. I, myself, simply am inclined to the belief that they exist in all flowing water.

J. Foster Crowell, M. Am. Soc. C. E.—In Table No. 5 of the paper, which gives the effect on the velocities of different openings of the valve, there is a very significant result which shows that a 24-inch valve can be largely closed without affecting very much the discharge, and it would be interesting to trace the relations. The curves on the diagram giving the values of the table show the effect very clearly. I think I could perhaps make it out, but I fear, as I have not prepared myself, it would be rather tedious for the other members present. I will, however, call your attention generally, which the author of the paper has already done, to the remarkable variations in the last column of the table and to the considerations which they suggest. It would appear that the water flowing in the full pipe section on reaching the lune-shaped opening is subjected to momentary compression at the orifice, which imparts a great increase of velocity to the current through the orifice. Were the sides of the orifice prolonged sufficiently, the velocity would be again decreased by the greater friction; but, for the short length of the valve contraction, the vis-inertia of the moving water is sufficient to overcome the increased friction, and the water passes through in a series of impulses with scarcely diminished volume of discharge. It may be that here is the solution of the oscillations in the flow observed in the gauges.

John W. Hill, M. Am. Soc. C. E.—The facility afforded by a partially closed stop valve in a water discharge pipe, for adjusting the resistance against which pumping engines are worked during contract and other trials, is often taken advantage of to produce a head on the pumps considerably greater than the normal pressure in the mains; by means of which the pumps may be caused to work under a pressure or head of 80, 90, 100 or more pounds, while the pressure in the main outside the engine-room may be maintained at 35 or 40 pounds, or at the static head of reservoir or stand-pipe, or at the usual service pressure. As the pressure on the pumps rises or falls, the stop valve or regulating valve is cautiously opened and closed a few turns or partial turns of the stem, by an observer in charge, who takes his cue from a pair of pressure gauges; one of which is connected to the discharge pipe

between the pumps and stop valve, and the other to the discharge pipe beyond the stop valve. Meanwhile the pumps may be worked at contract speed, or may be operated (as in direct service water-works) to meet the current demand for water.

I have made several duty trials of pumping engines in this manner, the only variable condition being the rate of discharge of the pumps while the steam pressure and head pumped against were constant; and at all other times all the conditions of pump delivery, head pumped against and steam pressure have been as nearly constant as it was possible by careful management to have them. In such cases the head in the discharge main between the stop valve and the pumps may be maintained at any desired pressure, while the head outside the engine room or beyond the stop valve, remains at the lower or usual service pressure.

But while I have used the principle of increased resistance by a partially closed stop valve in a pump discharge main to maintain a satisfactory head to pump against, it has never occurred to me that this might be employed to even approximately determine the discharge of the pumps; perhaps because of the more convenient and more reliable method generally adopted in such cases, viz., to calculate the actual displacement of the pump plungers from their net areas and travel, and allow an arbitrary loss of action or slip.

Apart from tests of pumping engines, situations may arise where it will be convenient to estimate the flow of water by means of the difference of pressures on opposite sides of a partially closed stop valve; but from present information on the subject I should be inclined to accept any such measurement as a very rough approximation indeed. If it be true that experimenters in hydraulics are not agreed upon the coefficients of resistance and discharge for the orifices of regular shape (round, square and rectangular), then how can we hope to reconcile the discrepancies which will arise when we attempt measurements of flow through variable lune-shaped orifices, with their coefficients of resistance and efflux changing with every change in the relative size of the orifice? and how will we apply an expression for discharge which may be obtained from experiments with a 24-inch Ludlow valve, to valves from the dozen or more other makers, or to valves of other sizes from the same maker, without special tests with each, which tests in themselves will generally dispose of the main question, viz., the determination of the discharge in a particular case.

The experiments of Mr. Kuichling are quite interesting, especially when the results are compared with those from Weisbach, with his simple gate valve, the differences in $\frac{F}{A}$, and in the coefficient of resistance (?) being accounted for, no doubt, by the difference in the forms and proportions of the Ludlow double disk and Weisbach simple sliding-

gate valve; and these differences serve to emphasize the difficulty surrounding attempts at estimating the flow of water through pipes by means of constricted lune-shaped valve orifices.

It is doubtful if the experiments have any practical value, because if it be required to measure the flow of water in a line of pipe of known diameter, it can be done more conveniently by means of accurate piezometers placed a measured distance apart and adjusted to a common datum plane; the difference of heads at the up and down stream stations (gauges) and diameter and character of wet perimeter of the pipe furnish all the necessary data for the use of Chezy or Kutter formula. This, of course, in situations where it is impossible or inconvenient to measure the discharge or flow by wier, or in tanks, or by reservoir.

John Thomson, M. Am. Soc. C. E.—In regard to the gauge illustrated in the paper by Mr. Kuichling, it is an instrument which ought to be in the hands of every engineer having to do with hydraulic operations. Its sensitiveness and yet relatively high range of reading, together with its uniformly exact indications, would render it invaluable in many places. For instance, if applied to a pump, a meter or a steam engine, any faulty throttling through the valves or channels could at once be detected. I am not fully persuaded, however, that the slip gauges and vernier as devised by Mr. Kuichling are the best arrangements that could be applied for reading the height of the columns. I have made a drawing of a differential mercury gauge intended for my own use in which a screw is disposed between the glass tubes, acting as a column to bind the head and base together. The screw is to be of 0.1 inch pitch, upon which a nut will be mounted, graduated to read in 0.01 and 0.005 inches. I am also of the opinion that steel indicators, floated upon the mercury, having sharply defined nicks or cross-lines, would be an assistance to accurate and ready reading. Such floats would require to be Bower-Barffed to resist corrosion, as they would be partially immersed in water. But these criticisms of detail are not to be taken as detractive of the gauge as a whole, the performance of which was highly satisfactory.

In view of a recent discussion in which I took part involving the matter of spring gauges as instruments of precision, particular attention is called to Mr. Kuichling's Table No. 2 in so far as the indications of the mercury columns are comparable to those of the spring gauge. Thus, in one case the spring gauge indicated a difference of 1 pound while the difference gauge denoted over 2 pounds; in another instance, the spring gauge showed no difference, while the actual change in condition amounted to nearly 1.35 pounds. As to the accuracy of the record there can be but little doubt. There was no chance for "argument" between the observers during the instant of any reading, as to whether, carpenter-like, it was "full" or "scant." The attention of each being intently

and solely directed to one column, even unconscious cerebration could not assist in improperly bringing the personal equation of the observers into unison. Moreover, after the complete series of observations had been concluded, the valve was reset to several known positions and the gauge again read. In all of such instances the observations were practically identical, and this was regarded as fair proof that the condition of the line, the valve, the gauge and the observers had not changed their rating.

I do not concur with Mr. Kuichling's opinion as to the cause of the oscillations of the mercurial columns. As will be seen by inspection of the drawings, the "legs" of the gauge were attached to the top of the conduit. Now, I take it that entrained air in a pipe-line travels at the top, being rolled along at a rate of speed probably less than that of the maximum velocity of flow. But, irrespective of the rate of travel, should even a globule of air pass the piezometric openings leading to the gauge, it would tend to disturb the *static* conditions which obtain thereat. And the fact that these fluctuations increased with the depression of the valve, in other words, were in a measure proportionate to the velocity of flow through the lune-shaped orifice, would seem to bear out this theory, in that any air driven down toward and thence through the lune-shaped opening would again ascend and impinge at a relatively high velocity against the upper surface of the pipe. If an experiment of this kind were to be duplicated, I would therefore suggest that the legs of the gauge be connected at the side or bottom of the pipe; or, better still, in the manner described by John R. Freeman, M. Am. Soc. C. E., in his paper on the hydraulics of fire streams, in which a circumferential channel is employed having a series of ducts communicating with the interior of the pipe. My present point may be illustrated by supposing that if Mr. Kuichling—instead of amply spreading the legs of his gauge, as he properly did—had connected them close up to opposite sides of the valve, then, in such an event, the suction of the discharge past the valve-disks would undoubtedly produce a negative effect somewhat proportionate to the increase of velocity at the orifice and a false conclusion might then have been deduced.

While Mr. Kuichling has chosen to treat his subject analytically, the practical importance of his work and its demonstration ought not to be left for doubtful recognition. It is, of course, to be expected that those, more or less familiar with throttling diaphragms and venturi-nozzles, have been aware of their relatively high discharging capacity when inserted in tubes or pipes of greater diameter, because such a condition is to the entire flow for an instant the friction of a point, so to speak, merging pressure into velocity. Nevertheless, speaking for myself, although having some reason to anticipate the results which Mr. Kuichling has presented, I question if I should have had the temerity,

without the assurance of this demonstration, to suggest placing in a force main of 2 feet diameter stop valves of, say, $1\frac{1}{4}$ or $1\frac{1}{2}$ feet diameter. And yet this, in my judgment, is what with perfect propriety might be done in analogous instances; as such an introduction, without resulting in any practical diminution of the discharging capacity of the line, would not only reduce the cost, but would greatly increase the ease and celerity with which the valves could be operated.

It is not intended by this to, in the slightest degree, disparage the ordinary frictional losses known to occur in flowing water; rather let it be taken as an exemplification thereof. In the *Engineering News* there was published some time past, several excerpts from the notes of the late W. J. McAlpine, in which occurred in effect this statement, which is worthy of record as a theorem: "As nature abhors a vacuum, so does water abhor an angle." But the action of a constricted opening, disposed transversely to the path of the current, results only in a simple deflection of a *portion* of the mass, and well illustrates the persistency to flow in a straight line, the abhorrence of an angle. Collateral to this it may be of interest to briefly describe a simple experiment, which I recently tried with the view of clearly fixing this fact in my own mind through the medium of ocular demonstration. A short piece of pliant rubber tubing, about three-fourths inch inside diameter, was connected to an ordinary faucet. The pipe was then curved to approximately a half circle, a small brass tube about one-fourth inch diameter was inserted so as to point towards the centre of said circular curve, and also another on the opposite side of the pipe projecting radially outward. The small tubes were, in fact, horizontal piezometers to the main section of pliant tubing. With the rubber tube discharging a full stream, the external piezometer would also discharge a full stream, but no flow would take place from the internal piezometer. This indicated no pressure upon the inner wall of the tube. The piezometers were then removed, and a section, about 2 inches long by, say, one-half inch wide, was cut from the inner wall of the loop, when the water would flow past the opening thus formed in a perfect stream, crystal-like and unbroken in contour. Obviously, the tangential tendency or persistency was entirely resisted by the exterior wall. It will, of course, be understood that the flow as just described would not continue at high velocities. From this the query naturally arises, what would be the probable difference in discharging capacity, supposing a valve to be situated in a circular loop, and so disposed that its disk would cut the flow from the exterior or from the interior side thereof?

In respect of Mr. Kuichling's reference to me as a co-acting observer, his close adherence to grammatical etiquette gives me undue honor: for in this work I was in nowise a principal, but was rather as "a student at the shrine of sages." Mr. Kuichling's paper is a distinct scientific addition to the subject of which it treats, and I am sufficiently honored in

having been the means of persuading him to prepare it. After the conclusion of the experiment, which consumed nearly all of a bright, pleasant Sunday, with kodak in hand I went up the bank of Mount Hope Reservoir, Rochester, N. Y., near where the gauge had been applied, and, turning quickly, caught a "snap shot" of Mr. Kuichling as he was mounting the stairs. The smile of satisfaction which yet lingered upon his features, filled the "field" of my instrument. He said that mine spilled over the bank. Possibly it did, for I had never taken part in a more interesting, instructive and successful demonstration, and my satisfaction at the time could not have been indicated in inches of mercury.

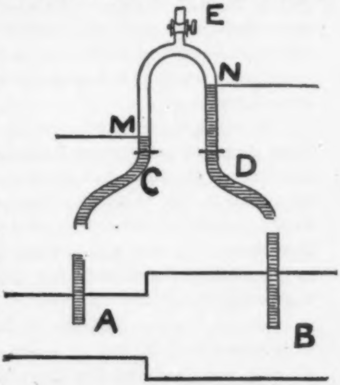
John C. Trautwine, Jr.—As to the cause of the oscillation observed in the heights of the mercury columns under a given opening of the valve, it is evidently, as our author intimates, a matter of individual opinion how much of these oscillations was due to the partial obstruction at the valve, and how much to variations in the barometric pressure upon one or both of the reservoirs. For my own part, my labors with Kutter's coefficient "*n*" of roughness have left me with a lively (perhaps exaggerated) sense of the disturbances caused by even very slight irregularities in the pipe; and I am therefore disposed to look rather to the obstructions at the valve, than (with the author) to barometric changes, for the cause of even the remaining slight oscillations observed in the mercury columns after the valve was fully opened. Even in the smoothest and straightest pipes and channels, the particles of water next to the walls must move very much slower than those nearer to the axis of the pipe, and this difference of velocity must produce lateral currents and eddies which cannot but cause variations in the piezometric pressure at a given opening in the pipe. Now the positive though partial obstruction caused by even a fully opened valve, must greatly aggravate this disturbance, and it seems to me that we ought to expect, at openings placed near such an obstruction, just such oscillations as are here recorded, independently of possible variations in the air pressures at the reservoirs. As remarked by the author, the oscillations, of course, decreased rapidly and almost uniformly (see Table No. 2) as the obstruction was diminished by the progressive opening of the valve; and it can hardly be doubted that a still further reduction of the oscillation would have been observed if the valve could have been removed altogether and a smooth length of pipe substituted for it. It will also be noticed that as a rule the oscillations were greater at the lower than in the upper gauge tube, as might be expected of oscillations due to the obstruction. It is true, however, that this distinction is much less marked, and therefore less conclusive, with wider than with narrower openings of the valve.

The author states that "the same (query, equal ?) oscillation was observed * * * on applying the gauge to the same line of pipe at a locality about 6 miles from the distributing reservoir, and at a time

when no change whatever was made in any valve or other fixture on the line"; but we are not told whether in this case there was a valve or other partial obstruction between the two piezometric openings. And, even if there were none, it seems to me it might still be a matter of conjecture whether the oscillations were due chiefly to barometric changes, or to those eddying currents which must exist even in practically "smooth" pipes. It would be interesting, in this connection, to have the results of similar experiments accompanied by careful and simultaneous barometric records taken at the two reservoirs.

We are not informed as to the time during which the oscillations took place; but, as the entire series of observations was made within "several hours," it may properly be asked whether the time occupied by the separate oscillations was sufficient to render admissible the assumption of the necessary barometric changes at the reservoirs. In the absence of the plates referred to, which no doubt show the relative elevations of the valve and of the lower reservoir, we may ask also whether and how it was known that the pipe just below the valve ran constantly full, especially under the smaller openings recorded. I am advised that the reason for the absence of records of experiments with openings of less than thirteen turns, is that the limit of the gauge was reached at that point.

R. FLETCHER, Assoc. Am. Soc. C. E.—Collignon* shows an ideal sketch of a form of differential piezometer (see Fig.) devised by Bélanger, which he describes substantially as follows: Small differences of piezometric columns may be obtained by joining together two small pipes fixed in the conduit, one at *A*, the other at *B*. These are terminated at *C* and *D* by a single curved glass tube, *CED*, at the summit of which an opening, *E*, is provided with a stop cock. The water mounts in the piezometer and compresses the contained air. The stop cock is opened and controlled so as to allow a part of the contained air to escape until the water appears



in both branches of the glass tube, when it is arrested, as at *M*, in one branch, and at *N* in the other. The difference of level between *M* and *N* measures by liquid column the difference of pressure sought.

The form thus described has the advantage of affording a differential

* "Cours de Mécanique Appliquée aux Constructions, 2me Partie, Hydraulique." M. Edouard Collignon, Paris, 1870.

piezometric column more than twelve times as long as the corresponding mercury column, and may be useful for measuring small differences of pressure if the conditions are not such as to cause extreme or long-continued oscillations. It has the further advantage of simplicity in detail and small cost. But the range of its adaptation is limited, as the use of a differential water column more than 3 or 4 feet high would be generally inconvenient. It may be presumed, also, that under pressures exceeding 80 to 100 feet, with a long line of pipe, the oscillations would be very troublesome.

It would appear that the oscillations observed by Mr. Kuichling may well be due to the recognized and unexplained irregularities in the flow of water under conditions calculated to secure the highest degree of uniformity. An assumption of sudden variations in atmospheric pressure would need strong confirmation from simultaneous barometric observations. Mr. Kuichling's valuable and interesting results are an important addition to our stock of hydraulic data.

George W. Rafter, M. Am. Soc. C. E.—Mr. Kuichling's paper brings to the attention of hydraulicians an interesting, and to some extent important, line of experimentation, more especially because the stop valves used were much larger than those used by Weisbach, who, thus far, is the only experimenter who has published results of this character. The analytical portion of the paper may, moreover, be denominated elegant, by reason of the ingenious treatment which the purely theoretical side of the subject has received. In reference to the appliances used and the deductions from the observations, the paper, however, admits of criticism; and there are a number of important discrepancies which it is hoped the author of the paper will clear up in his final discussion.

The method of calibration, by reason of apparently eliminating the error due, not only to the impurity of the mercury, but to variations in diameter of the tube, is ingenious, and its author should receive especial credit for it. On this point, however, some confusion apparently exists, as Mr. Kuichling refers to a graduation of his tube in inches and tenths. If such a graduation was actually made and used, the error due to change in diameter of the tubes is not eliminated and it would vitiate the result. Following this thought further, it may be noted that the equivalent of an inch of mercury is given as 1.0493 feet of water, or 1 foot of mercury balances 12.59 feet of water, that is to say, the specific gravity of the mercury used was, for the actual temperature and elevation, 12.59, instead of about 13.55, as it should be for pure mercury. It is hoped that Mr. Kuichling will explain whether the apparent discrepancy here is due to impurity of the mercury or to variation in size of his tubes, as upon this point will hinge very largely the real utility of his experiments.

Again, it may be noted, the record shows a loss of 0.135 inch of

mercury. Even after the gate is entirely open, this loss taking place according to the paper in a length of main of 17.1 feet (which in a length of 1 000 feet, the ordinary unit for statement of hydraulic gradient) amounts to a loss of 8.28 feet. At the time of making the experiments, the total fall between the two reservoirs, connected by the 24-inch main, in which the stop gate experimented upon occurs, was 112.89 feet, giving, for a total length of connecting main of 46 867 feet, a rate of gradient of 2.41 feet per 1 000. There is, however, a slight bend in the special *Y* branch included between the two points of attachment of the apparatus, but the small amount of deviation from a right line occurring here cannot be taken as explaining the large value of the deduced gradient of 8.28 per 1 000 feet for full discharge. In my opinion, this fact alone should make us very cautious in accepting these results as otherwise than accidentally correct. This remark is further emphasized by the wide variation in value of the coefficients given in Column 10 of Table No. 3, in comparison with those of Weisbach, in Column 11.

Again, the propriety of selecting the 24-inch gate of the Mount Hope Reservoir gate-house for these experiments may be fairly questioned, in view of the possibility of the disturbing influence of the special; which, while an exceedingly small quantity with full gate and its consequent low velocity of a little less than 4 feet per second, is nevertheless an important factor with a partially throttled gate and the resulting high velocity through the same. The location selected admitted conveniently of a distance of only 17.1 feet between points of attachment for the difference-gauge apparatus, a distance which the great fluctuations in the earlier stages of the experiments shows to be entirely insufficient for accurate work. Moreover, there are at least two points on the same pipe line where the experiments could be made and a stretch of nearly straight pipe of several hundred feet on either side of the gate obtained. A statement of the reasons in detail, by Mr. Kuichling, of why this particular gate was selected, in view of the obvious objections in preference to either of the others, will also assist greatly in determining the real utility of his experiments.

These criticisms are advanced with the hope that, inasmuch as his results are so widely different from those of Weisbach, which many hydraulicians have been in the habit of considering classic, Mr. Kuichling may be able to clear up the dark points in reference to them which now apparently exist.

D. Farrand Henry, M. Am. Soc. C. E.—Mr. Kuichling's paper on the loss of head through a 24-inch valve interested me very much, and I think his observations and deductions will be useful in the future. But when he speaks of the continuous pulsation of the mercury in his gauge when the valve was fully opened and the current normal, he touches a strange and to me yet a mysterious property of flowing water. These fluctuations in the strength or velocity of the current were

observed by M. Darcy when using a Pitot's tube—an instrument very similar to Mr. Kuichling's gauge—but they were never measured until during the measurement of the outflow of the great lakes. I invented and used the telegraphic current meter—as noticed in my pamphlet on the "Flow of Water in Rivers and Canals," and the lake survey reports. When the meter was first placed in the current the most noticeable thing was the marked irregularity in the beat of the sounder—each "click" representing one revolution of the submerged wheel—at times slow and stately, and again with a buzz almost continuous. Wherever I placed my meter in these rivers, in the Chicago Water Works tunnel or in the tail race of a mill, the same changeableness in the correct velocity was manifest. These pulsations of the current were greater at the bottom and least at the surface, but without regularity as to time or force, the common maxima being from five to perhaps twenty seconds apart, while every ten or fifteen minutes would come a rush of the current which would set the sounder buzzing. I noticed the same thing at Niagara. Standing at the base of the Fall, or under the sheet, when the principal maxima came the earth would tremble under one's feet, and in the whirlpool rapids the waters would clash together and the center waves seem to rise above the level of the eyes. I have some notes also of the survey for the Cuba cable, which show that these pulsations also affect the flow of that wonderful current—the Gulf stream. In fact, what we term "uniform flow" of water seems almost as unstable as the motion of the wind. To measure these fluctuations I placed a Morse paper register in the circuit, each revolution of the current wheel making a dot on the paper, and I kept a few of these paper slips, which I enclose, as they may be of interest, being probably the only autographic record extant of the current of a great river.* As the Morse register was found to be rather irregular in its action, depending perhaps upon the thickness of the paper passing through the rolls, which thus retarded it more or less, I had the observer make a pencil mark across the paper every half minute as it passed the stylus. They were taken in the St. Clair River in 1868, but the notes of the survey are buried in the archives of the office of the Engineer Bureau at Washington, so I cannot give their position in the river, but most of them are evidently in the deeper portion of the river, while one set (September 16th) was taken near shore, where the water was not over 5 or 6 feet in depth. I tabulated hundreds of these records, but was never able to establish any law of pulsation.

Several years subsequently, when chief engineer of the water works at Detroit, Mich., I placed a glass mercury gauge in an upper room in the office, which was high enough not to make the tube inconveniently long, and I used to watch it at night when everything was quiet, when few taps

* The paper slips here referred to were exhibited when the paper was read, but it is impracticable to publish them here.

would be opened, and the regular night use and the waste was all the demand on the supply. At such times I would turn the full pressure on the gauge, and the mercury would commence slowly sweeping up and down the tube, the fluctuations being ordinarily from 3 to 6 inches every quarter of a minute or less, but rising often to 8 inches or more. This would keep up as long as I cared to watch the pulsation. The fluctuations noted by Mr. Kuichling might therefore have been due to this curious and as yet unexplained instability of the velocity in flowing water.

James Duane, M. Am. Soc. C. E.—In reading Mr. Kuichling's paper one is struck most forcibly by the great waste of algebraic ingenuity shown in the construction of formulas which the author admits are of but doubtful utility in his special case—especially as they would not be of general applicability. In fact, the whole question is one for experimental solution only, and is not susceptible of satisfactory analytical investigation. The pith of the entire article seems to be contained in the last column of the last table, where the coefficients of discharge are given. That these are given to the fifth place of decimals seems an unnecessary refinement, as these values probably contain errors in the second place of decimals at least. Further, while we are willing to admit that the coefficient of discharge through the throttled valve when half open may approximate to unity, it is difficult to see how, for any ratio of opening whatever, it can ever exceed unity.

In filling sections on 36 and 48-inch pipe lines, the writer has had opportunities of approximately determining the coefficient of discharge for different degrees of valve opening under quite a range of heads. The method of making these observations was as follows: the new pipe lines to be filled had blow-offs in the hollows, and, as is usual with us, fire hydrants placed at the summits acted as air cocks. When a section of the pipe line was to be filled, the blow-offs were first opened to insure the emptying of the pipe, so that we knew just how many cubic feet were necessary to fill that section. The blow-offs were then closed. The filling was done from a 6 or 12-inch branch supplied from the general distribution, and as near the summit as possible, so as to insure a light and practically uniform back pressure. The men stationed at the air cocks were instructed to close them as soon as the water showed, so that there was no waste at these points. The time of turning on the water and of its appearance at each air cock was recorded.

In each case the feeding gates were opened a certain number of turns before being set, and a roughly shaped piece of card-board placed against the valve, and the lune-shaped opening carefully traced thereon. The area of this tracing was determined by a planimeter, and is believed to have been correct within very close limits. The vertical distance between the point where the feed pipe became completely filled below the gate and the center of a spring pressure-gauge located just above

the feeding gate was measured, and the pressure was determined from time to time during the operations of filling. The employment of the spring pressure-gauge is the weak link in the experimental chain. We have never been able to obtain spring gauges that could be regarded as instruments of precision, their employment usually resulting in errors of 2 or 3 per cent. at least.

Two examples covering about the greatest range of head that occurred in filling a 36-inch line recently are appended.

1*st.* 6-inch gate open 1-inch ; area = .035 square foot; head, 12.1 feet.

Q = 34.360 cubic feet; time, thirteen hours; coefficient = 0.75.

2*d.* 12-inch gate open 1-inch; area = .058 square foot; head, 52.0 feet.

Q = 39 100 cubic feet; time, four hours thirty minutes; coefficient, 0.75.

It will be seen that these coefficients agree fairly well with those deduced by Mr. Kuichling for about the same amplitude of valve opening.

E. Kuichling, M. Am. Soc. C. E.—The discussion appears to be confined to comments on the observed oscillations of the piezometrical mercury columns, the details of the pressure-difference gauge, and the practical value of the results of the experiments made.

The remarks of Messrs. Herschel, Henry and Thomson amply corroborate the existence of the oscillations referred to, but still leave a satisfactory explanation of their cause in doubt. While eddies or internal disturbances of flow may account for much of the fluctation, yet the effect of momentary differences of barometric pressure at the two reservoirs, nine miles apart, cannot safely be ignored; and that such differences or rapid variations in the pressure of the atmosphere at any given place do occur, is well known to all who have attempted to do leveling with either a mercurial or an aneroid barometer. During the summer of 1891, the writer made hundreds of observations for obtaining topography on the water-shed of Hemlock Lake, New York, with a delicate aneroid having a range of only about 4 inches and a diameter of dial of 5 inches ; and he frequently observed sudden variations in the pressure, amounting at times to several hundredths of an inch (from 10 to 40 feet of elevation), which lasted only a few minutes, or even seconds. On all these occasions the instrument was at perfect rest and observed from the same position. A sharp watch was kept, particularly for the purpose of detecting such atmospheric waves, and they were found in all kinds of places and at nearly all hours of the day, but more frequently about noon. Through these observations, as well as many others since made, the writer is led to believe that such momentary waves may account for some of the mercurial fluctuations.

A similar phenomenon was noticed in observing the rise of water in a large reservoir, about 1 600 feet long, 400 feet wide and 14 feet deep, which was receiving near one end the uniform discharge of a gravity

conduit at the rate of nearly 11 cubic feet per second, the outlet having been tightly closed. The observations were made near the middle of the long side of the reservoir in a cistern of 6-inch iron pipe, set rigidly so as to project about 2 feet into the water, and provided with a hole near the bottom only one-fourth of an inch in diameter. With little or no wind at the time, a slight oscillation of the water surface, without any apparent regularity or uniformity, was always detected with a hook-gauge; the amplitude of these waves in the cistern ranging from 0.05 to 0.20 inch at irregular intervals varying from one to three minutes.

With reference to the remarks of Mr. Trautwine, it may be stated that the pressure-difference gauge described was applied several times to a certain straight and clear section of the 24-inch cast-iron pipe connecting the two reservoirs mentioned, the gauge being placed midway between two taps inserted in the top of said pipe about 1 000 feet apart, and coupled thereto with ¾-inch wrought-iron pipe. The locality was on a plateau about three miles from the upper reservoir, and an air-valve near the gauge showed that the water was free from entrained air. After the gauge had been properly adjusted, the fluctuations took place as described, both with the conduit in full operation from the upper to the lower reservoir, and with the lower portion of the conduit shut off by an intermediate stop-valve, while the discharge from a 6-inch blow-off was being carefully measured over a suitable weir. The purpose of the experiments was to ascertain with the gauge the actual loss of head on a measured length of said conduit, for known discharges, and thence to deduce the corresponding coefficients of friction. It should also be remarked that the blow-off was located in a depression about one-half mile below the gauge, and that the fluctuations of the mercury were very frequent and large on all occasions.

On the other hand, during a similar application of the gauge, late last year, to various portions of the ten-mile section of 24-inch pipe conduit between Hemlock Lake and the aforesaid upper reservoir, the fluctuations were found to be very slight, ranging from only 0.02 to 0.03 inch at intervals of two to four minutes, while during these intervals the mercury remained nearly stationary. It is therefore seen that on long, clear and comparatively straight sections of 24-inch pipe, free from entrained air, and discharging at the rate of about 11 cubic feet per second, we may have at one time extensive fluctuations of the mercury, while at another time the fluctuations are almost imperceptible. For this circumstance the most reasonable explanation seems to be, the presence or absence of differences of barometric pressure at the communicating bodies of water.

The theory of Mr. Thomson, that the fluctuations are largely due to entrained air, is open to the criticism that the existence of a bubble of compressed air at the top of the main pipe, or even in the tube leading to the difference-gauge, cannot affect the results, since differences of pres-

sure are indicated by the instrument, and because the assumed globule of air must have the same pressure as the adjacent molecule of water. In the case of the escape of large entrained air bubbles from a submerged pipe, it is probable that a series of shocks would occur which would be indicated by fluctuations of pressure; but, in the experiments described, no appearance of any such air bubbles at the outlet in the reservoir was detected. The suggestion of Mr. Thomson to make use of a circumferential pressure-channel around the conduit, instead of attaching the gauge to single taps at or near the top of the pipe, is good, although in the case of large pipes the application of such a device in the field is somewhat difficult.

It is also to be remarked, in response to the comments of Mr. Trautwine, that the difference in the magnitude of the simultaneous oscillations in the two legs or tubes of the gauge is due to the difference in diameter of the said tubes, since the volume of mercury displaced or transferred from one leg to the other for a given difference of pressure must be the same. Were the two tubes exactly alike in diameter, the rise of mercury in the one would be precisely equal to the fall in the other. Greater differences of pressure between the points where the taps are inserted in the pipe are naturally attended with greater variations of head of mercury, and also with relatively greater fluctuations or oscillations as exhibited in the table. The 24-inch pipe behind the valve experimented with was kept full by the back-pressure from the reservoir, as will be seen from the drawing.

With regard to the construction of the instrument, the writer has no doubt as to its capability of improvement. From the experience with the apparatus depicted, it was found that the slides for the arms or tubes must admit of quick motion and be set rapidly, as the mercury seldom remains quiet; and the question therefore arises, whether a greater refinement of measurement than the limit of error in setting is necessary. Practically, the slides can be set to within 0.01 inch, and it therefore seemed that a vernier scale reading to this limit was sufficiently accurate for measuring the mercury head or distance between the two slides. The introduction of suitable floats or pointers on the mercury would, doubtless, be an improvement; but, in this event, care must be taken to have both the interior of the instrument and the mercury perfectly clean, otherwise a slight impurity lodging between the float and the glass tube might cause a failure of correct indication.

The method of calibrating the gauge, as described in the paper, is conceded by Mr. Rafter to be correct, but still he seems to be dissatisfied with it in some particulars. By actually measuring the head of water in feet, and with uniform graduations of inches on the scale of the gauge, the errors due to differences of diameter of the tubes at different levels are duly exhibited in the paper, and are seen to be so very slight (the average differing only a few thousandths of an inch from the ex-

treme), that it was considered justifiable to make use of the mean value of a head of 1 inch of mercury thus found, in terms of feet of water. For the fact that 1 inch of this mercury balanced 12.59 inches of the same water which was used in the experiments, instead of 13.55 inches, the writer does not venture now to offer an explanation. The metal was procured of a reputable dealer and supposed to be pure. The results obtained are, however, in no wise vitiated, as Mr. Rafter appears to think, since the comparisons are given throughout for the equivalent feet of water. Any other experimenter with stop valves may therefore easily compare his work with that of the writer by using heads in feet instead of in inches of mercury.

In relation to the practical value of the experiments little need be said, since the estimate of such work is necessarily governed to a large extent by the experience in practical hydraulics of the person making it. Without impugning in the slightest degree the skill of any one who fails to discover any utility in such work, it seems to the writer that a computation of discharge through any orifice based upon the use of a well-established coefficient, is preferable to one which is based upon the displacement of a pump piston or plunger, whose actual loss of action, or slip, is entirely unknown. Again, in the construction of a large pipe conduit line, it may be very desirable to know whether the use of valves which are smaller in diameter than the pipe itself is admissible. From the coefficients obtained, it now becomes possible to compute with close approximation the resulting loss of head involved in such use of smaller valves. Neither is it necessary to make a rating of each particular valve, unless great accuracy is required, since Mr. Duane has pointed out in his remarks a close agreement in the values of the coefficients for a 6, 12 and 24-inch valve for about the same amplitude of opening. In ascertaining the delivery of a conduit, also, whose exact diameter and internal condition are unknown, but in which a duplicate stop-valve is available, the above results are directly applicable with much greater presumption of accuracy than would be secured by the use of the Chezy or Kutter formula, as proposed by Mr. Hill. It is not enough to merely measure the loss of head between a number of points in the pipe line, and then assume the coefficient of friction and the diameter, since both of these elements are important factors in the discharge. The results of such a computation with an old line of cast-iron pipe, whose components were made at several different foundries, might easily differ ten per cent., or even more, from the truth.

A few words as to the "waste of algebraic ingenuity shown in the construction of the formula," may also be permitted. Such formulas serve to express the laws underlying the flow of water through orifices, etc., much better and more compactly than tables, diagrams, or statements; and it should be the aim of every engineer, or experimenter to find these laws from the facts at hand. To simply publish a mass of

undigested observations may be good for the printer, but their perusal becomes a source of intense exasperation to a busy professional man who wishes to apply the principle to a somewhat different case. If such work has no other value, it at least serves to point out to other seekers after truth what labor to avoid, and possibly also what lines of further examination to follow. Efforts of the kind referred to cannot therefore be called wasted, but may rather be termed sign-posts on the perplexing road to knowledge, whose multiplication should rather be encouraged than discouraged.

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THE CONTINUOUS GIRDER AS A TIPPER.

By C. H. LINDENBERGER, Assoc. Am. Soc. C. E.

The problem of finding the strains on the Tipper has been pretty thoroughly discussed by Mr. Clemens Herschel, M. Am. Soc. C. E., years ago. Nevertheless, the formulas obtained by his method are long and tedious in their application, and later writers like Professor Howe and Professor Du Bois only indicate the general manner of solution and do not give equations that can be readily used in practice, especially in complex cases such as a variable moment of inertia, loads varying in amount in all the spans, etc.

It may interest the members of this society if a method is demonstrated by which any one who can deduce the moments at the supports for the comparatively simple case of "supports on a level," can immediately write the equations for the moments for the Tipper, for the form in which it usually occurs in practice. The analysis is new and the method quite different from those of previous authors.

The Tipper is a continuous girder resting on four supports, but is distinguished by the fact that its two middle ones rest on a bar or

unyielding framework and this again is supported at its center. The accompanying figure will explain it.

The first support is numbered 1 and also the first span. P_n is a weight on the nth span whose length is l_n and a_n is its distance from the left support. M_n is the moment at the nth support, and will be considered positive when there is tension on the upper chord or flange. h_n is the distance that the nth support lies below a given axis of reference. R_n is the reaction at the nth support and is positive when it acts upward.

The only case that need be discussed in this paper is that where the axis of reference is a line passing through all four of the supports which are on a level for no load on the girder, then evidently $h_2 = -h_3 = h$. Also the reactions at the middle supports are necessarily equal.

We will suppose three cases:

First, that the supports are on a level and are rigid and unyielding and let us call the moments M'_2 and M'_3 and the middle reactions R'_2 and R'_3, the girder being loaded in any manner whatever.

Second, let all the load be removed and let one of the middle supports sink a certain distance $= h$ and the other rise an equal amount. Let us call the moments M''_2 and M''_3 and the reactions R''_2 and R''_3. The supports are to be rigid and unyielding as before.

Third, let the previous load be again placed upon the girder and let us designate the moments by M_2 and M_3 and the two middle reactions by R_2 and R_3. It is evident that these are due to the combination of the effects due to the two previous cases, or in other words,

$$M_2 = M'_2 + M''_2 \qquad M_3 = M'_3 + M''_3$$
$$R_2 = R'_2 + R''_2 \qquad R_3 = R'_3 + R''_3.$$

The difficulty which suggests itself is that we do not know what the proper deflection is, but it will be shown that it is only necessary to assume that it is the proper one for the given loading.

Now, in the second case, since the deflection of each of the middle supports is equal in amount and opposite in direction, the moments are proportional to the amount of that deflection (since there is no load upon the girder). In other words, we have

$$M''_2 = \quad F_2\, h \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$
$$M''_3 = -F_3\, h \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where F_2 and F_3 are constants for the particular girder. Also, since the values of R_2 and R_3 must be equal,

$$R'_2 + R''_2 = R'_3 + R''_3, \text{ whence}$$

$$R'_2 - R'_3 = -(R''_2 - R''_3) \qquad (3)$$

The principles of statics give equations for the difference of these reactions which are entirely independent of any theory of elasticity, the first one of which is as follows:

$$R'_2 - R'_3 = \frac{M'_2}{l_1} - \frac{M'_3}{l_3} + \frac{2(M'_2 - M'_3)}{l_2} + \Sigma P_1 \frac{a_1}{l_2}$$
$$+ \Sigma P_2\left(1 - \frac{2a_2}{l_2}\right) - \Sigma P_3\left(1 - \frac{a_3}{l_3}\right).$$

Now, for convenience, let us put

$$\frac{1}{l_1} + \frac{2}{l_2} = \frac{1}{f_1} \qquad \frac{1}{l_3} + \frac{2}{l_2} = \frac{1}{f_3}$$

$$\Sigma P_1 \frac{a_1}{l_1} + \Sigma P_2\left(1 - \frac{2a_2}{l_2}\right) - \Sigma P_3\left(1 - \frac{a_3}{l_3}\right) = Q$$

and we obtain

$$R'_2 - R'_3 = \frac{M'_2}{f_1} - \frac{M'_3}{f_3} + Q;$$

and from the above, remembering that in the second case $Q = 0$, we obtain by the aid also of equations (1) and (2),

$$R''_2 - R''_3 = \frac{M''_2}{f_1} - \frac{M''_3}{f_3} = M''_2\left(\frac{1}{f_1} + \frac{1}{f_3}\frac{F_3}{F_2}\right) = -M''_3\left(\frac{1}{f_1}\frac{F_2}{F_3} + \frac{1}{f_3}\right)$$

$$\frac{R'_2 - R'_3}{R''_2 - R''_3} = -1 = \frac{\frac{M'_2}{f_1} - \frac{M'_3}{f_3} + Q}{M''_2\left(\frac{1}{f_1} + \frac{1}{f_3}\frac{F_3}{F_2}\right)} = -\frac{\frac{M'_2}{f_1} - \frac{M'_3}{f_3} + Q}{M''_3\left(\frac{1}{f_1}\frac{F_2}{F_3} + \frac{1}{f_3}\right)}$$

Whence

$$M''_2 = -\frac{M'_2 f_3 - M'_3 f_1 + Q f_1 f_3}{f_3 + f_1 \frac{F_3}{F_2}}$$

$$M''_3 = \frac{M'_2 f_3 - M'_3 f_1 + Q f_1 f_3}{f_3 \frac{F_2}{F_3} + f_1}$$

Therefore

$$M_2 = M'_2 + M''_2 = \frac{f_1\left(M'_2 \frac{F_3}{F_2} + M'_3\right)}{f_3 + f_1 \frac{F_3}{F_2}} - \frac{Q f_1 f_3}{f_3 + f_1 \frac{F_3}{F_2}} \qquad (4)$$

$$M_3 = M'_3 + M''_3 = \frac{f_3\left(M'_2 + M'_3 \frac{F_2}{F_3}\right)}{f_3 \frac{F_2}{F_3} + f_1} + \frac{Q f_1 f_3}{f_3 \frac{F_2}{F_3} + f_1} \qquad (5)$$

The terms F_2 and F_3 can be computed if the construction is given and the correct theory is known. It is to be noted that so far the argument is deduced from a consideration of the laws of statics alone and nothing is said of the method by which the moments are computed.

If the two end spans are equal and the girder is so constructed as to be symmetrical in all its parts with reference to the middle of the center span, we will, according to the ordinary theory of the continuous girder, have $M'_2 = -M'_3$ or $\frac{F_2}{F_3} = 1$. Let l be the length of each end span and ml that of the middle span, then $f_1 = f_3 = \frac{ml}{2+m}$ and the above becomes

$$M_2 = \frac{M'_2 + M'_3}{2} - \frac{Qml}{2\,(2+m)} \quad \text{.................}(6)$$

$$M_3 = \frac{M'_2 + M'_3}{2} + \frac{Qml}{2\,(2+m)} \quad \text{.................}(7)$$

If these equations are compared with those of Mr. Herschel, it will be found that, for the case he gives, the results are identical, but it is evident that they are practically simpler, easier to remember, and also much more general.

To show that $F_2 = F_3$ for the case just mentioned for variable moment of inertia, use the formula published in the journal of the Franklin Institute for January, 1891, and reduce by making $G_1 = T_3$ and $G_2 = T_2$.

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THE TRANSITION CURVE WHOSE CURVATURE VARIES DIRECTLY AS ITS LENGTH FROM THE P. C. OR POINT WHERE IT CONNECTS WITH THE TANGENT.

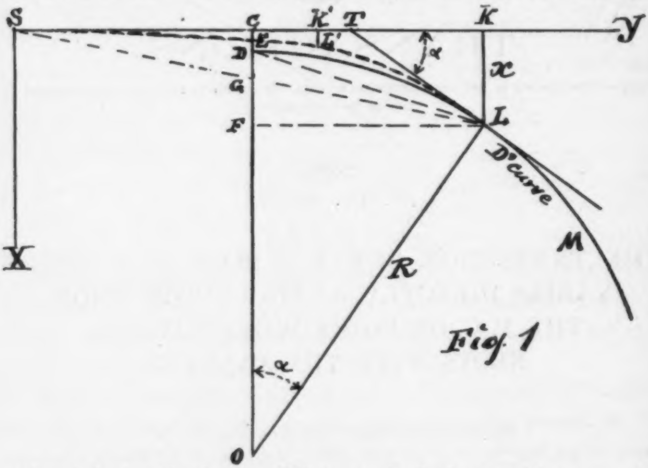
By WILLIAM CAIN, M. Am. Soc. C. E.

The ideal transition curve, to pass from a tangent to a circular curve of given degree, is one whose curvature is zero at the point where it leaves the tangent (P. C.) and increases directly as its length, measured along the curve, to where it connects with the circular curve, at which point it should have the same tangent and rate of curvature as the circular curve. By the use of such curves on railroads or street car lines to ease off the ends of circular curves, the super-elevation of the outer rail for the circular part is gradually attained without shock, and the sudden change from the tangent to a circular curve, so often experienced on unadjusted railroad curves, with its annoying and damaging lurch, is avoided.

A. M. Wellington, M. Am. Soc. C. E., was the first to propose such a transition curve, and recently Mr. C. R. Howard has given his treatment of the same curve. As both these authors develop the theory, to some extent, from approximate considerations, it occurred to the author to

endeavor to make an exact solution, and it is here presented. The solution is simple and direct, and requires only a knowledge of a few elementary principles of the calculus. Certain constants will be computed and certain useful approximate formulas will also be deduced.

In Fig. 1, let the transition curve *SEL* begin at *S* and be tangent to the axis *SY*. Refer the curve to rectangular axes *SY* and *SX* and denote the co-ordinates of any point *L* by *X* and *Y* ($KL = x$ and SK



$= y$) and the length of curve *SEL* by *s*. At *L*, the transition curve (or spiral) has the same tangent and degree of curvature (D°) as the circular curve *DLM* (of radius *r*) with which it connects. A similar notation would apply to any other point on the curve as *L'*.

The tangent at *L* makes the angle α with the tangent *SY*; therefore when α is expressed in "circular measure" or in "arc," the "curvature" at the point *L* (x, y) is represented by,

$$\text{limit}\left(\frac{\Delta \alpha}{\Delta s}\right) = \frac{d\alpha}{ds} = \frac{1}{r};$$

and this, by the definition of the curve, must equal a constant $(2a)$ times *s*.

$$\therefore \frac{d\alpha}{ds} = \frac{1}{r} = 2as \quad \text{.................... (1)}$$

whence,

$$\alpha = as^2 \quad \text{.......................... (2)}$$

since $\alpha = o$ when $s = o$. From (1) we have likewise $r = \infty$ when $s = o$.

From the differential triangle, we have—

$$dx = ds \sin. \alpha = ds \sin. (as^2) \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$dy = ds \cos. \alpha = ds \cos. (as^2) \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

As these expressions cannot be integrated in finite terms, the equation of the curve in terms of x and y cannot be obtained.

In practice, the curve OL will be run by measuring N chords of c feet each along the curve. When these chords are sufficiently short, they can be regarded of the same length as the arcs subtended by them, hence we shall always write,

$$s = Nc \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

for the length of curve from the origin S to any point considered, as L.

In running circular curves, such a chord length should be taken that the arc and chord are practically equal. Thus for 1, 2, 3 and 4 degree curves, chord lengths of 100 feet may be taken; for 8-degree curves, 50-foot chord lengths should be used, and so on; in which case the degree of any curve D° (as for DLM at L) is equal to the radius of a 1-degree curve divided by r

$$\therefore D^\circ = \frac{18\,000}{\pi r} = \frac{36\,000}{\pi} as \ldots\ldots\ldots\ldots\ldots (6)$$

To express the arc α (equation 2) in minutes, we notice that its ratio to a semi-circumference whose radius is one, is $\frac{d}{\pi}$ and multiplying this by 180×60, we find from (2) and (5)

$$\alpha \text{ (in minutes)} = \frac{\alpha \text{ (in arc)}}{\pi} 180 \times 60 = \frac{as^2}{\pi} 180 \times 60$$

$$\therefore \alpha \text{ (in minutes)} = a \frac{180 \times 60}{\pi} c^2 N^2.$$

Now, as a and π are constant, we see that α varies with c^2N^2, and if we assume, as Mr. Howard does, for any length of chord c, that α is the same for the same value of N, and, in minutes, is equal to 6 N^2 (as by the above equation it varies as N^2), we have—

$$\alpha \text{ (in minutes)} = 6\, N^2 \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Of course, we have a right to use any other constant than 6 as the coefficient of N^2 (and, doubtless, others will be used in time in addition), but having assumed (7) as a fundamental equation, we must find the corresponding value of a by equation (7) and the equation just above it; whence—

$$a = \frac{\pi}{1800\, c^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

On substituting this value of a in (6), we have—

$$D^\circ = \frac{18\,000}{\pi r} = \frac{36\,000}{\pi} as = \frac{20s}{c^2} = \frac{20N}{c} \qquad (9),$$

which gives the degree of curvature of the transition curve, N stations of c feet each, from the origin s. If it connects there with the circular curve, the tangent and degree of curvature at the connecting point are the same for both curves.

By multiplying both sides of equation (9) by $\frac{s}{200}$ we have—

$$\frac{D^\circ s}{200} = \frac{D^\circ Nc}{200} = \frac{20N}{c} \cdot \frac{Nc}{200} = \frac{N^2}{10};$$

but from (7), α in degrees $= \frac{6N^2}{60} = \frac{N^2}{10}$; hence—

$$\alpha \text{ (in degrees)} = \frac{D^\circ s}{200} = \frac{D^\circ Nc}{200} \qquad (10)$$

In Fig. 1, at O, the center of the circular curve DLM, having at L the same tangent and degree of curvature as the spiral SEL, draw a perpendicular OC upon the tangent SY, cutting the spiral at E and the circular curve produced at D and draw the chords SL and DL. Then $LOC = \alpha = LTK$ and $\frac{DL}{100}$ = number of 100 foot stations in arc DL $\therefore D^\circ \frac{\text{arc } DL}{100}$ = total angle turned in length $DL = \alpha = \frac{D^\circ s}{200}$ by (10); whence—

$$\text{arc } DL = \tfrac{1}{2} s = \tfrac{1}{2} \text{ length of spiral } SEL \qquad (11)$$

From this we have, since for flat arc $LD = LE$ nearly, $LE = \frac{1}{2}$ SEL or point E is nearly at middle of spiral. The "gap" $CD = q$ between the tangent sy and the circular curve may then be regarded as the offset at the middle of the transition curve from circular curve to tangent sy.

We can deduce two useful formulas by aid of (9) above.

$$c = \frac{20\,N}{D^\circ} \qquad (12)$$

$$Nc = s = \frac{20\,N^2}{D^\circ} \qquad (13)$$

We shall next deduce expressions for computing x and y for given values of s. From equation (3) we have, developing sin. (as^2) by the usual formula—

$$dx = ds\left(as^2 - \frac{1}{6}(as^2)^3 + \frac{1}{120}(as^2)^5 - \text{etc.}\right);$$

whence integrating and making the constant zero, since $x = o$, when $s = o$, and placing for brevity α for (as^2) from (2), we have—

$$x = s\,\alpha \left(\frac{1}{3} - \frac{\alpha^2}{42} + \frac{\alpha^4}{1320} - \text{etc.} \right) \ldots\ldots\ldots\ldots\ldots (14)$$

Proceeding similarly with $dy = ds \cos. (as^2)$, and we deduce,

$$y = s \left(1 - \frac{\alpha^2}{10} + \frac{\alpha^4}{216} + \frac{\alpha^6}{9360} + \text{etc.} \right) \ldots\ldots\ldots (15)$$

From (8), $a = \frac{\pi}{1800c^2}$; hence α in equations (14) and (15) is given (in length of arc on a unit circle) by—

$$\alpha = as^2 = ac^2N^2 = \frac{\pi}{1800} N^2 = .001745329\ N^2;$$

$$\therefore \log. \alpha = 7.2418774 - 10 + \log. (N^2) \ldots\ldots\ldots\ldots\ldots (16)$$

The above value of α can be obtained likewise from equation (7). It is independent of c, as in fact was assumed from the first; but since $s = Nc$, the values of both x and y above, vary directly as c. Hence, if we compute from (14) and (15) successive values of x and y for $c = 100$, corresponding to $N = 1, 2, 3 \ldots 15$, and denote these values, respectively, by—

$$X_1, X_2, X_3 \ldots X_{15},$$
$$Y_1, Y_2, Y_3 \ldots Y_{15},$$

the subscripts denoting the station to which they refer; then when c has any other value than 100, we have by (14) and (15),

$$x = \frac{Xc}{100} = \frac{0.2\,NX}{D^\circ} \ldots\ldots\ldots\ldots\ldots\ldots (17)$$

$$y = \frac{Yc}{100} = \frac{0.2\,NY}{D^\circ} \ldots\ldots\ldots\ldots\ldots\ldots (18)$$

The last forms being derived from (12) by putting for c its value

$$\frac{20\,N}{D^\circ}.$$

The results of the computation are given in the adjoining table under the corresponding values of N, given at the tops of the columns.

In computing the values of X given by (14), it was found that the results could be found correctly to the last figure given, for $N = 1, 2$, by taking only the first term of the parentheses and neglecting the others; for $N = 3, 4, 5, 6, 7, 8, 9, 10, 11$, two terms are needed, and for $N = 12, 13, 14, 15$, only three terms are required.

For the values of Y, two terms of the parenthesis in (15) were used up to $N = 9$; for greater values of N three terms only are required. A six-figure table of logarithms was used except for the larger values, where a seven-place table proved desirable.

The series is very converging for the small values of α used, and, in fact, would answer for much larger values.

N.	1	2	3	4	5	6	7	8
X......	.058178	.46542	1.57074	3.72316	7.27121	12.5628	19.9445	29.760
Y......	100.000	199.999	299.993	399.969	499.904	599.763	699.488	799.002
F......	.25000	.25000	.25000	.25000	.25001	.25002	.25005	.25011
Q......	.002909	.046542	.235611	.744632	1.81785	3.7692	6.982	11.910
α......	6′	24′	54′	1° 36′	2° 30′	3° 36′	4° 54′	6° 24′
Δ......	2′	8′	18′	32′	50′	1° 12′	1° 38′	2° 07′ 59″

N.	9	10	11	12	13	14	15
X........	42.351	58.051	77.188	100.078	127.024	158.310	194.197
Y........	898.201	996.958	1095.104	1192.442	1288.735	1383.706	1477.033
F........	.25018	.25026	.25038	.25056	.25077	.25104	.25137
Q........	19.071	29.056	42.519	60.180	82.819	111.278	146.448
α........	8° 06′	10° 00′	12° 06′	14° 24′	16° 54′	19° 36′	22° 30′
Δ........	2° 41′ 58″	3° 19′ 57″	4° 01′ 55″	4° 47′ 51″	5° 37′ 45″	6° 31′ 37″	7° 29′ 25″

The angle made by a chord drawn from station 0 (S) to station N, with the axis SY (Fig. 1), will be designated by Δ_n. This angle is readily found from the formula—

$$\tan.\ \Delta_n = \frac{X_n}{Y_n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (20)$$

Thus, for Δ_{12} we have $\tan.\ \Delta_{12} = \dfrac{100.078}{1192.442}$; whence $\Delta_{12} = 4° \ 47' \ 51''$.

The values of the angles Δ are inserted in the adjoining table under the proper value of N, and the values of α derived from equation (7) are placed above for comparison, from which we note that if we express Δ to the nearest minute that

$$\Delta = \frac{\alpha}{3} = 2N^2 \text{ (in minutes)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (19)$$

except for $N = 15$, where the error of using the formula is 35 seconds, a matter of no practical importance. There is no use to be made of (19), however, except in checking roughly the values of Δ in the table. If the table is extended, as it easily can be, to any desirable values of N, the values of tan. Δ must all be computed by dividing the X by the

corresponding Y and finding the angle Δ corresponding. As in practice, the table will always be at hand, there is no need for formula (19) except in checking for the smaller values of N.

The angle made by any chord connecting any two stations of the curve with the Y axis (line SY), will be designated by i with two subscripts, giving the station numbers through which the chord is drawn; thus i_{3-9} indicates the angle made by the chord joining stations 3 and 9 with the Y axis. Its value is readily found from the equation,

$$\tan. i_{3-9} = \frac{X_9 - X_3}{Y_9 - Y_3} = \frac{40.7803}{598.208}$$

to be $i_{3-9} = 3^\circ\ 54'\ 00''$.

Similarly, we find the inclinations of all the chords to the Y axis, these chords being drawn between any two stations whatsoever.

A demonstration of a more rapid way of computing these angles to the nearest minute will be given further on.

Line Q in the table gives the product qD°, where q is the distance CD (Fig. 1) and D° the degree of the circular curve LA. We find this product as follows:

Call for brevity, R_1 = radius of a 1-degree curve = 5729.65; then (Fig. 1), $R = \frac{R_1}{D^\circ}$ and $q = KL + OF - OD = x + R \cos. \alpha - R$.

Therefore from (17),

$$q = \frac{.2NX}{D^\circ} + \frac{R_1 (\cos. \alpha - 1)}{D^\circ}$$

$$\therefore\ Q = qD^\circ = 0.2\ NX - R_1 (1 - \cos. \alpha) \dots\dots\dots\dots (21)$$

Calling now the ratio of q to the ordinate at $L = F$, we have,

$$F = \frac{q}{x} = \frac{qD^\circ}{.2NX} = \frac{Q}{.2NX} \dots\dots\dots\dots\dots\dots\dots (22)$$

In computing the quantities Q and F given in the table, a seven-figure logarithmic table was used except for $N = 1$ to 6 inclusive, where a ten-place table was needed. This last computation, though, is not absolutely necessary, as we shall see presently that for N small, the value of F must approach one-fourth, as given in the table. If we assume it then at 0.25 for $N = 1, 2, 3, 4$, we have from (22) $Q = .05NX$ for these values of N as given in the table.

The fundamental formulas given above are all that are needed for solving any problem concerning the transition curve.

Approximate Formulas.

On referring to the table of quantities, we notice that the ordinate X at the middle of any length of curve is nearly one-eighth that at the end. Thus $\frac{1}{8} X_{12} = 12.51$, and this is nearly equal to $X_6 = 12.56$. We can see that this is generally true if we write $x = \frac{1}{3} as^3$ approximately from (14) on neglecting all terms after the first; then designating by x_0 the ordinate corresponding to $s_0 = \frac{1}{2}s$, we have $x_0 = \frac{1}{8} (\frac{1}{3} as^3)$ or one-eighth the extreme ordinate x.

The equation $x = \frac{1}{3} ay^3$ is that of the cubic parabola, and we see that the equation $x = \frac{1}{3} as^3$ closely approximates to it for very flat arcs.

We have found, for flat arcs, that radius OD (Fig. 1), drawn from O perpendicular to SK produced, nearly exactly bisects the curve SEL; hence SG is nearly equal to LD, and since $\varDelta$ (in arc) $= \frac{CG}{SG}$ nearly, and $\frac{\alpha}{2}$ (in arc) $= DLF$ (in arc) $= \frac{FD}{LD}$ and $\varDelta = \frac{\alpha}{3}$ nearly, we have, approximately,

$$\frac{\varDelta}{\left(\frac{\alpha}{2}\right)} = \frac{CG}{FD} = \frac{2}{3}$$

or since $CG = \frac{KL}{2} = \frac{x}{2} \therefore FD = \frac{3}{4} x$, and,

$$DC = FC - FD = x - \tfrac{3}{4} x = \tfrac{1}{4} x = q.$$

This last result explains why $Q = \frac{q}{x}$ in the table, is $\frac{1}{4} = 0.25$, for small values of N.

Now, since $CE = x_0 = \frac{1}{8} x$ (nearly), as shown above, and $q = \frac{x}{4}$ (nearly) we have approximately,

$$CE = \tfrac{1}{2} CD = \tfrac{1}{2} q;$$

so that the curve SEL nearly bisects the distance q between the tangent and the circular curve.

We shall now proceed to deduce formulas for quickly computing the angles i to the nearest minute.

We have seen that the formula (19), $\varDelta = \alpha \div 3$, is correct to the nearest minute up to and including $N = 14$ (and near enough for $N = 15$). In fact, it is exact to the second, up to and including $N = 7$. Referring now to equation (14) and neglecting all terms in the parentheses after the first, and calling x^1 the approximate value of x_1 we have

$$\frac{x^1}{s} = \frac{1}{3} \alpha;$$

and this equals $\varDelta$ to the nearest minute within the limits taken.

We should naturally infer, within the same limits, that the angle i (in circular measure) could be expressed by a similar approximate formula,

$$i = \frac{x_1^1 - x^1}{s_1 - s}$$

where $x_1^1 - x^1$ is the difference in the ordinates, computed by the approximate formula above, and $s_1 - s$ is the length of curve between them. This formula reduces to the preceding when x^1 and s are zero, in which case i reduces to Δ.

We have..........$x^1 = \frac{1}{3}\,\alpha s = \frac{1}{3}\,as^3 = \frac{1}{3}\,ac^3\,N^3$;

hence,

$$i = \frac{x^1_1 - x^1}{s_1 - s} = \frac{a}{3}\,\frac{c^3\,(N_1^3 - N^3)}{c\,(N_1 - N)} = \frac{ac^2}{3}\,(N_1^2 + N_1\,N + N^2).$$

Replacing ac^2 by its value $\frac{\pi}{1\,800}$ (equation 8) and multiplying both sides of the equation by $\frac{180 \times 60}{\pi}$ to reduce to minutes, we have,

$$i \text{ (in minutes)} = 2\,(N_1^2 + N_1\,N + N^2) \qquad (23)$$

This gives, approximately, the angle i in minutes, for the inclination of the chord passing through stations N and N_1. It is evidently immaterial which we take as the forward station, as the same method of procedure will lead to the same formula (23), whether N_1 or N be regarded as the forward station.

As n application, let $N_1 = 10$, $N = 5$;

$$\therefore\ i_{5-10} = 2\,(10^2 + 10 \times 5 + 5^2) = 350' = 5^\circ\,50',$$

which is correct to the nearest minute, and, in fact, differs only a few seconds from the exact value. It is found, by trial, that the formula can be safely used up to $N = 15$ for computing i to the nearest minute. Where a whole table has to be computed, it is more expeditious to proceed by the method of differences. On changing N to $(N + 1)$ in (23), we get the angle i for the chord from station $(N + 1)$ to station N_1. Subtracting (23) from this we have the angle between the two chords from N to N_1 and $(N + 1)$ to N_1 equal to (in minutes),

$$\text{1st difference} = 2\,(N_1 + 2\,N + 1) \qquad (24)$$

As N increases one at a time, the first difference increases $4'$; hence,

$$\text{2d difference} = 4'.$$

We observe from the formula (23) that for $N = 0$, $i = \Delta = 2N_1^2$, which agrees with (19), and for $N = N_1$ we find that the right member becomes $6N^2$, which by (7) is exactly equal to the α corresponding to the

station. Hence, starting with $N = 0$ in (23), which gives Δ, and increasing N one at a time, we compute the corresponding i's until $N = N_1$ is reached, when the α at stations $N = N_1$ is found. As N again increases one at a time the corresponding i's are found.

In Fig. 2 is given an illustration for $N_1 = 5$ $\therefore$ first difference $= 12 + 4N$ by (24) and second difference $= 4$.

For $N = 0$, angle between chords 05 and 15 $= 12'$

$N = 1$, " " " 15 " 25 $= 16'$

$N = 2$, " " " 25 " 35 $= 20'$

Similarly for the others, starting with $\Delta_5 = 50'$ and adding the successive differences above, we deduce at once the values given in the figure: $i_{1-5} = 50 + 12 = 62'$, $i_{2-5} = 78'$, $i_{3-5} = 98'$, $i_{4-5} = 122'$, $i_{5-5} = \alpha_5 = 150'$, $i_{5-6} = 182'$, and so on.

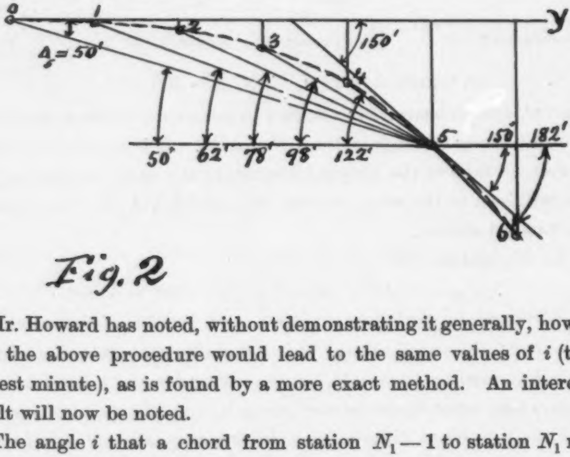


Fig. 2

Mr. Howard has noted, without demonstrating it generally, however, that the above procedure would lead to the same values of i (to the nearest minute), as is found by a more exact method. An interesting result will now be noted.

The angle i that a chord from station $N_1 - 1$ to station N_1 makes with the Y axis, is found from (23) by changing N to N_{1-1}.

$$\therefore i = 6N_1^2 - 6N_1 + 2.$$

Subtracting this from the α at $N_1 = 6N_1^2$, we have $\alpha - i = 6N_1 - 2$.

If N_1 is the point of connection with the circular curve, we have, $D^\circ = \frac{20N_1}{c}$, and the first deflection from the tangent on the circular curve for a chord of c feet is $\frac{1}{2}\ 60\ D^\circ\ \frac{c}{100} = 6N_1$ minutes.

This is greater by 2 minutes always than the angle between the tangent at station N_1 and the chord from station $N_1 - 1$ to station N_1,

as we have just found the latter angle to equal ($6 N_1 - 2$) minutes. This is as it should be, for from the definition of the curve the curvature increases regularly up to the point of connection with the circular curve, at which point alone the transition curve has exactly the same rate of curvature as the circular curve.

Having given above the methods for computing, either exactly or approximately, all needed elements of the transition curve, only a hint remains to be given as to the method of running in the curve. By formulas (17) and (18) x and y can be quickly found, by aid of the tabular values of X and Y, and the stations located; otherwise, with a table of values of Δ, α and i, the curve can be run by the method of deflection angles, as in the case of a circular curve, and with equal facility.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
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TRANSACTIONS.

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529.

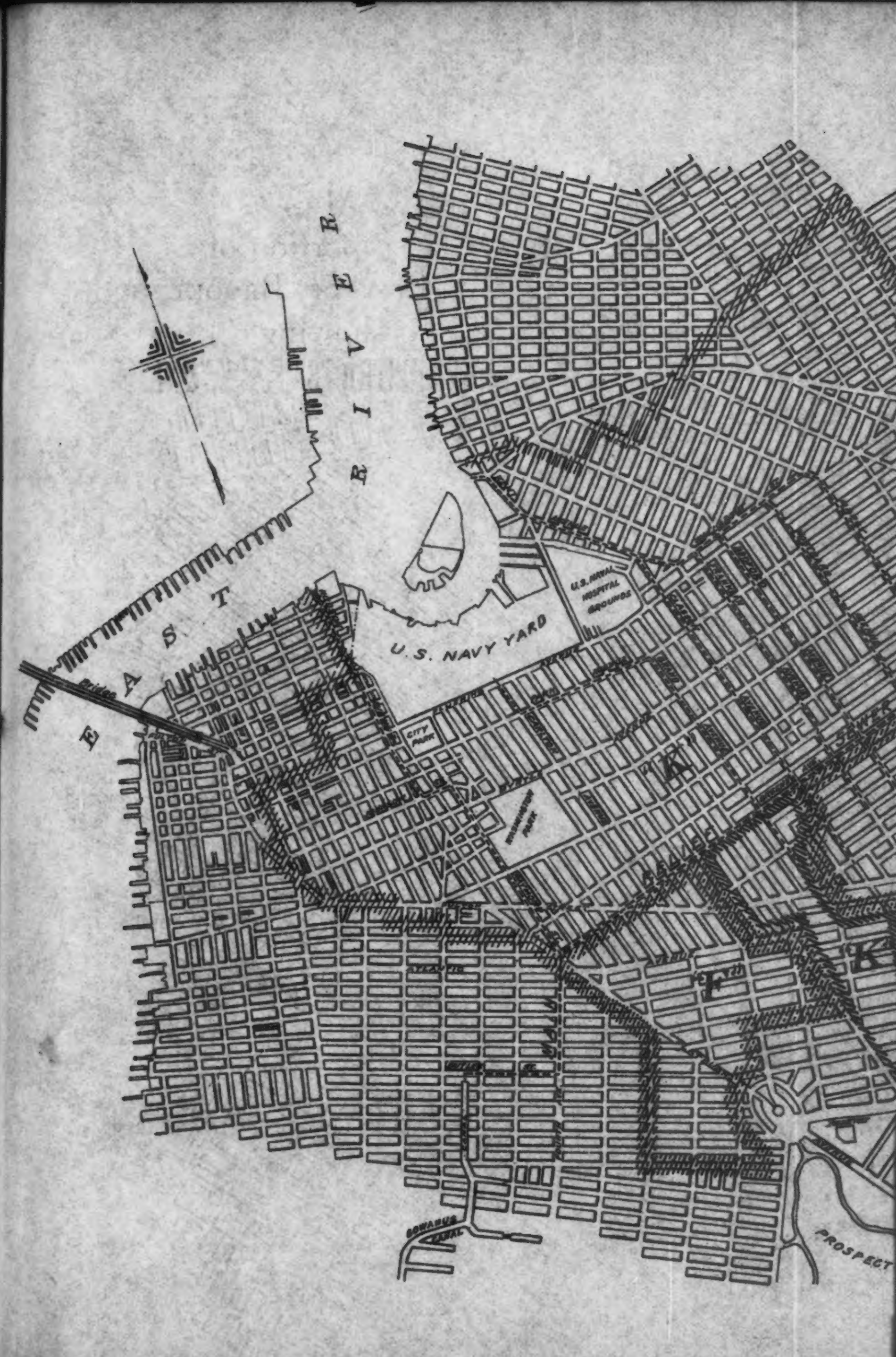
(Vol. XXVI.—May, 1892.)

THE MAIN RELIEF SEWER OF BROOKLYN.

By WILLARD BEAHAN, M. Am. Soc. C. E.

WITH DISCUSSION.

The relief of the overcharged sewers of our older and growing cities is one of the problems in engineering now before us. The Main Relief Sewer of the City of Brooklyn, N. Y., has at the outset the merit of an explanatory name. It is now completed, with marked success, by the Department of City Works of Brooklyn, of which Mr. John P. Adams is Commissioner, Robert Van Buren, M. Am. Soc. C. E., Chief Engineer. L. Russell Clapp, M. Am. Soc. C. E., was Assistant Engineer in charge. The western portion of Long Island, on which the city is situated, has rugged topographical features, which grow less marked as the Narrows are approached, but which form the distinctive feature of the site. The city is divided into sewer districts, the boundary lines of which are the dividing ridges in the secondary or tertiary drainage. Each district is distinct in system, the combined system of sewers is used, and the main sewer of each district empties into tide water. The sewers are of various dates of construction; some are of vitrified pipe, some of cement pipe, and the main district


EAST RIVER
U.S. NAVY YARD
U.S. NAVAL HOSPITAL GROUNDS
CITY PARK
GOWANUS CANAL
PROSPECT
"A"
"F"
K


U.S. NAVAL HOSPITAL GROUNDS
"A"
"F"
K

PLATE XLII.
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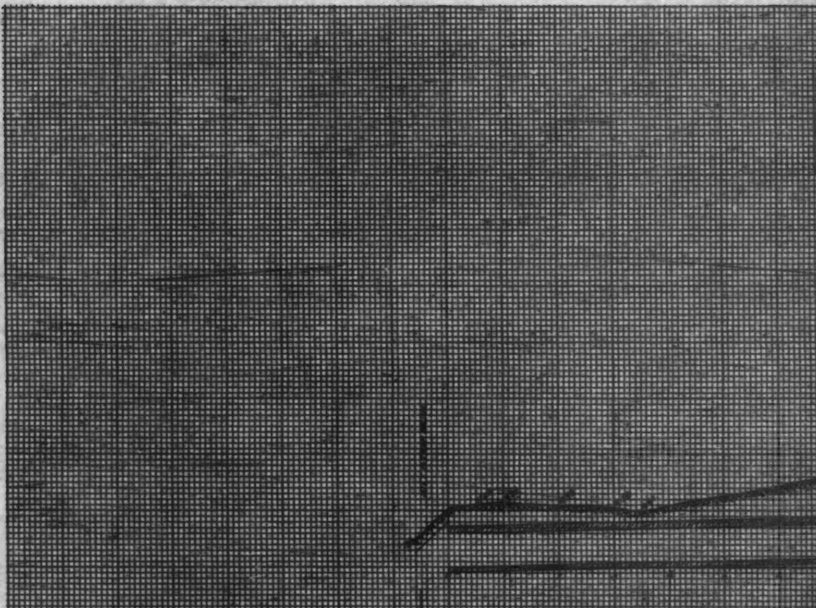
BEAHAN ON
BROOKLYN RELIEF SEWER.

Map
of a portion of
The City of Brooklyn
showing
SEWER DISTRICTS, "F," "K," & "L."



MAIN RELIEF SEWER.

Section I.

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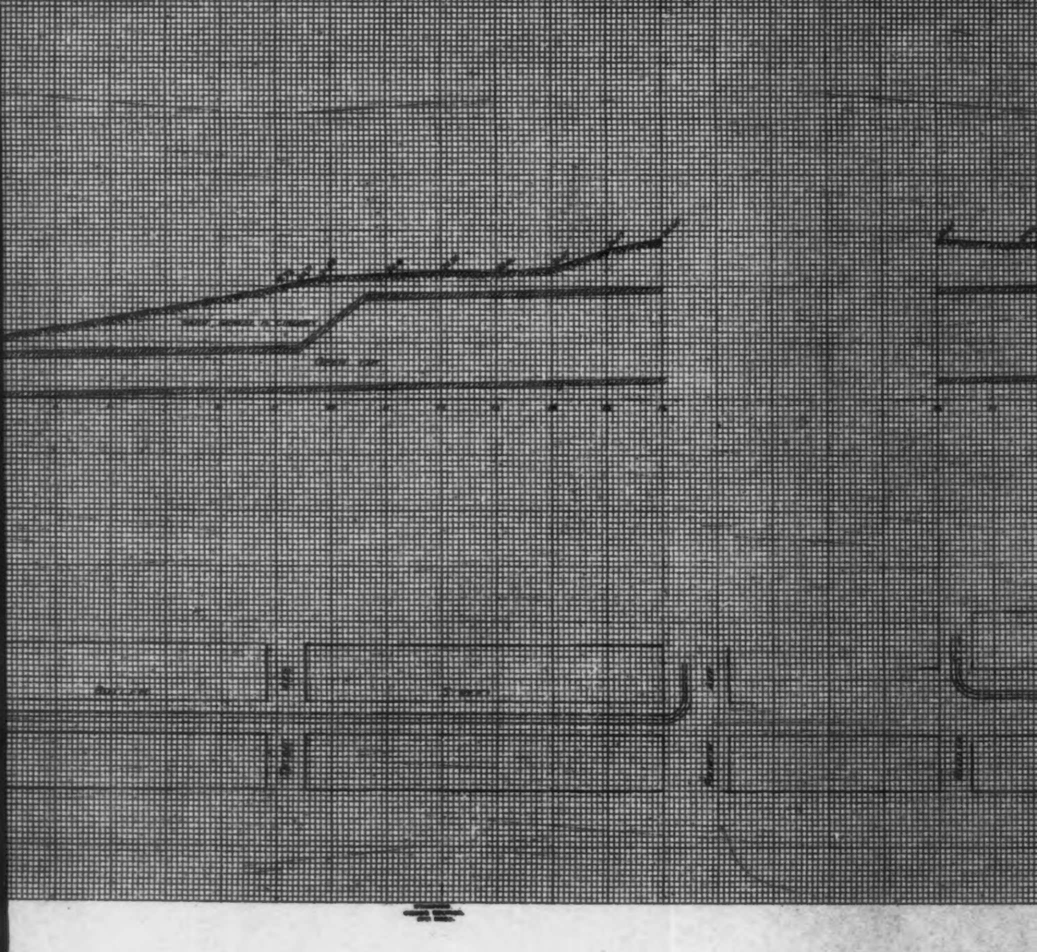

PLATE XLIII.
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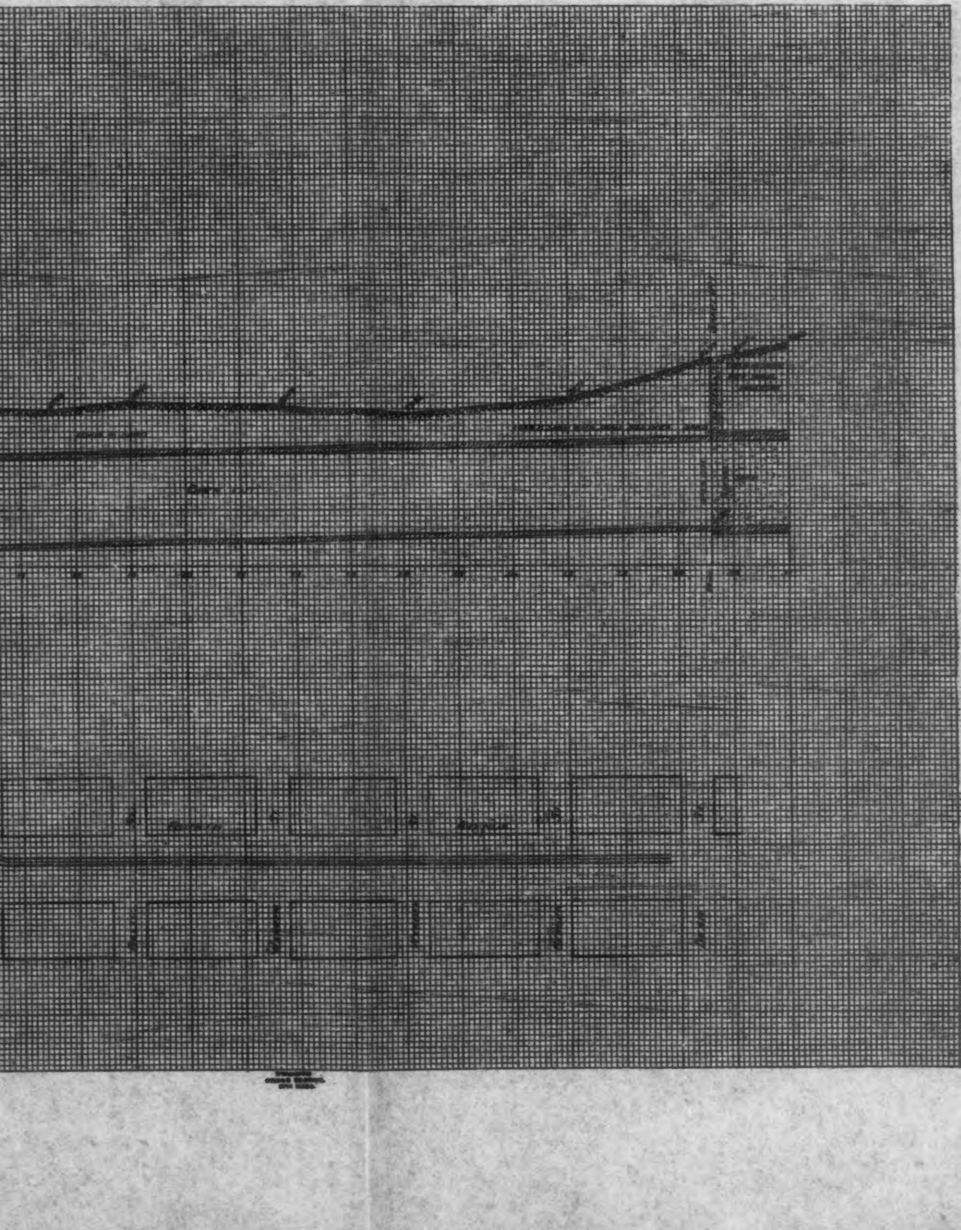
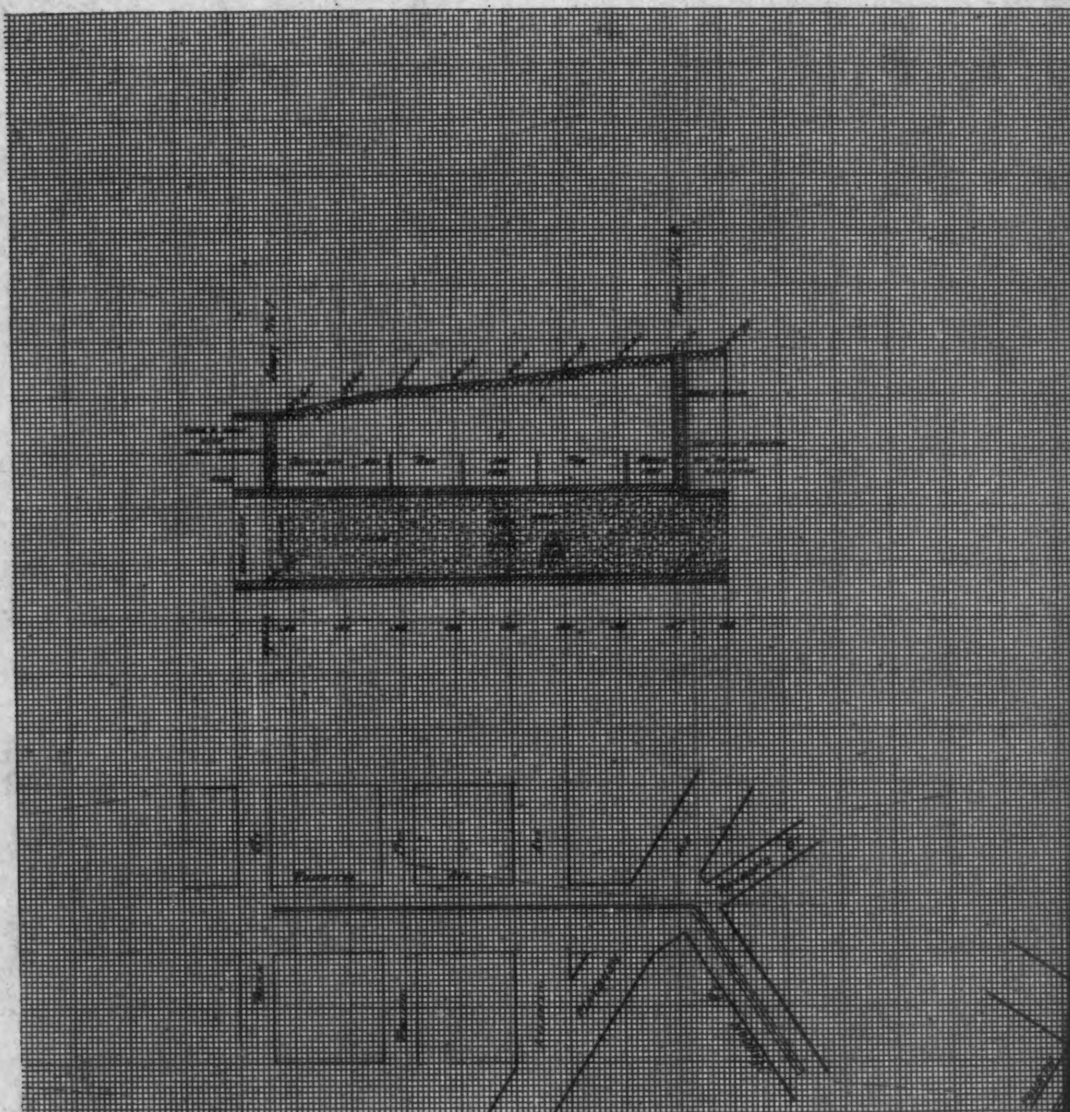
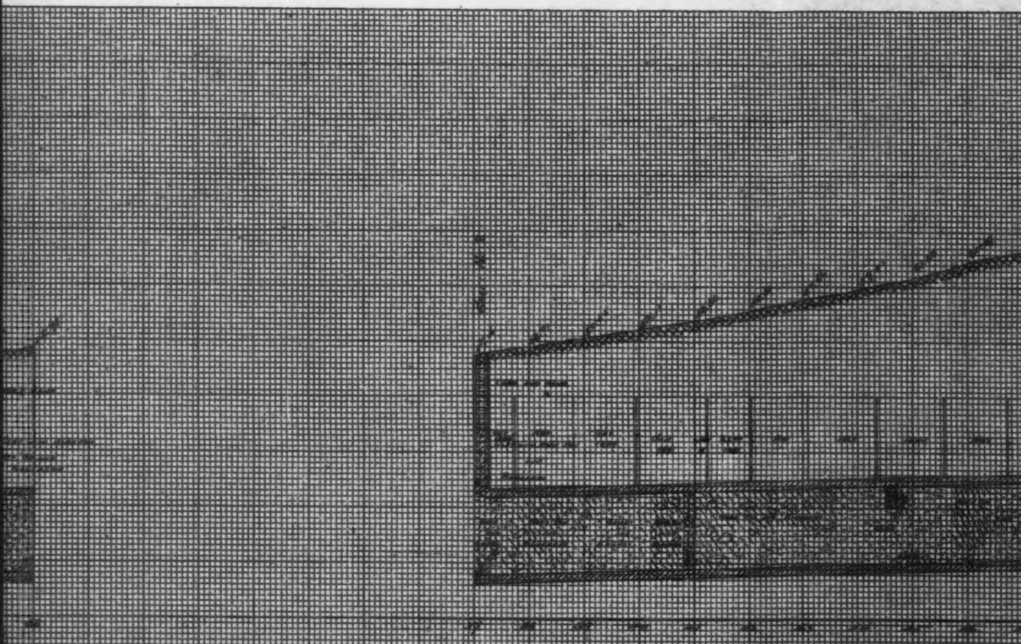
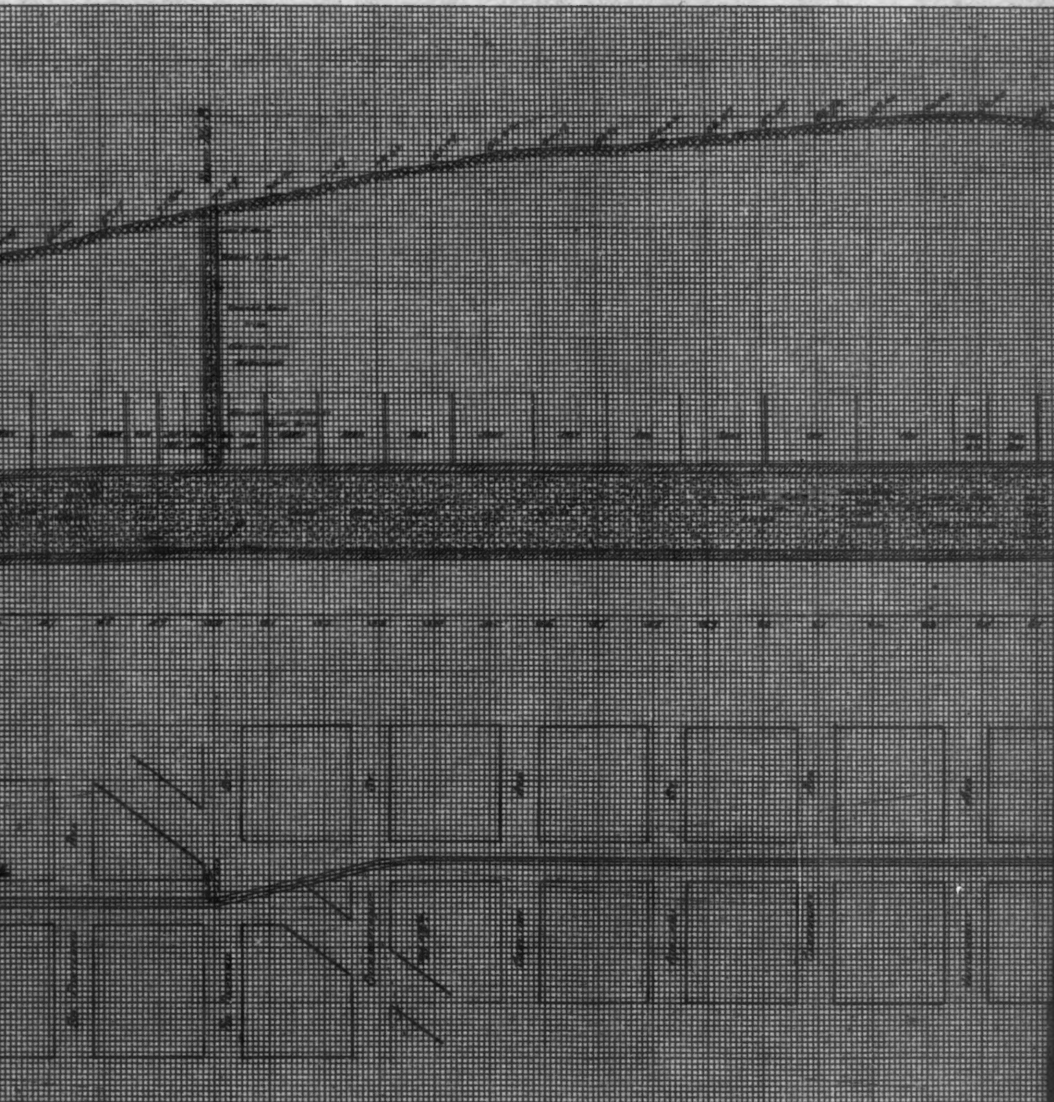
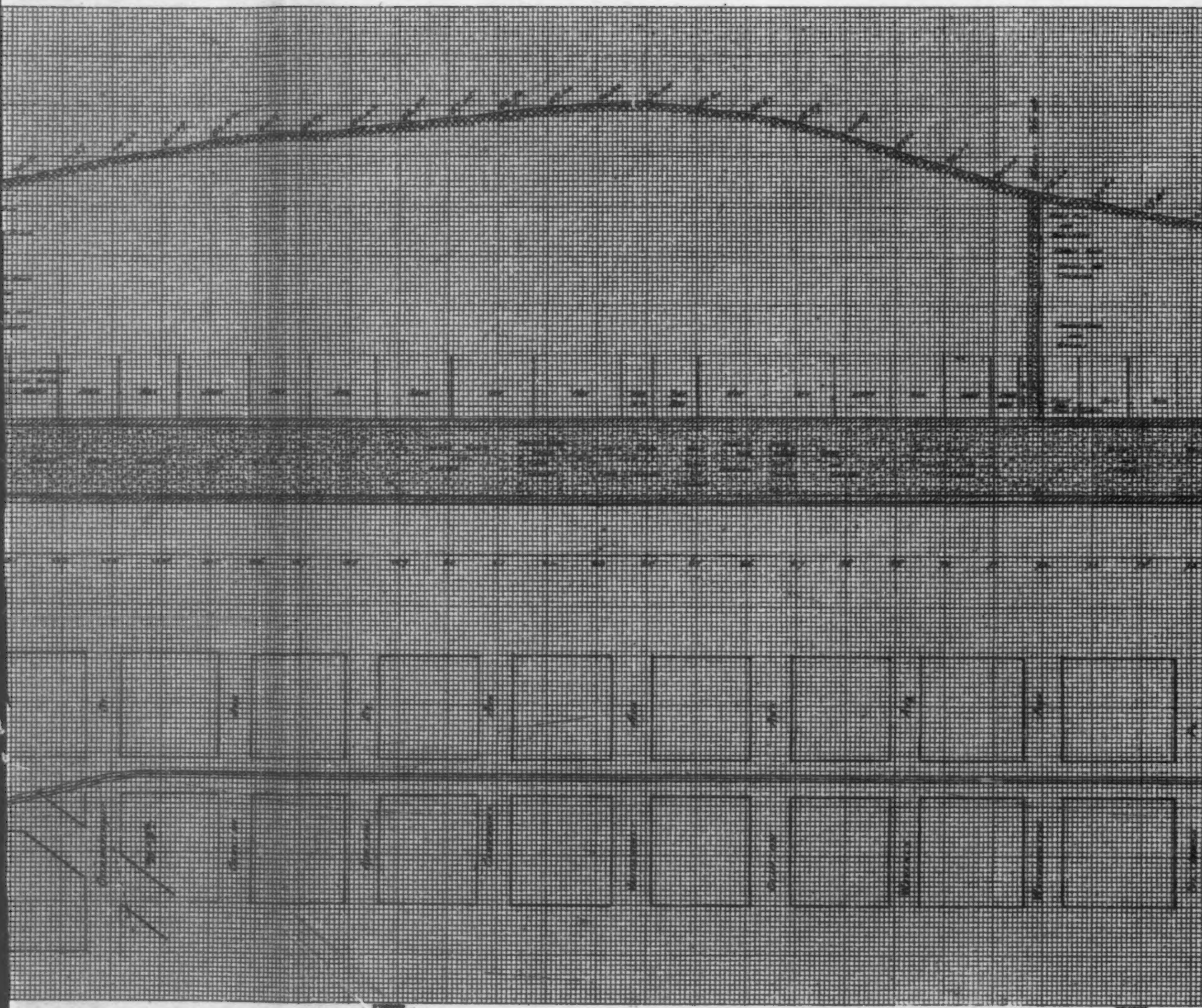
BROOKLYN RELIEF SEWER.

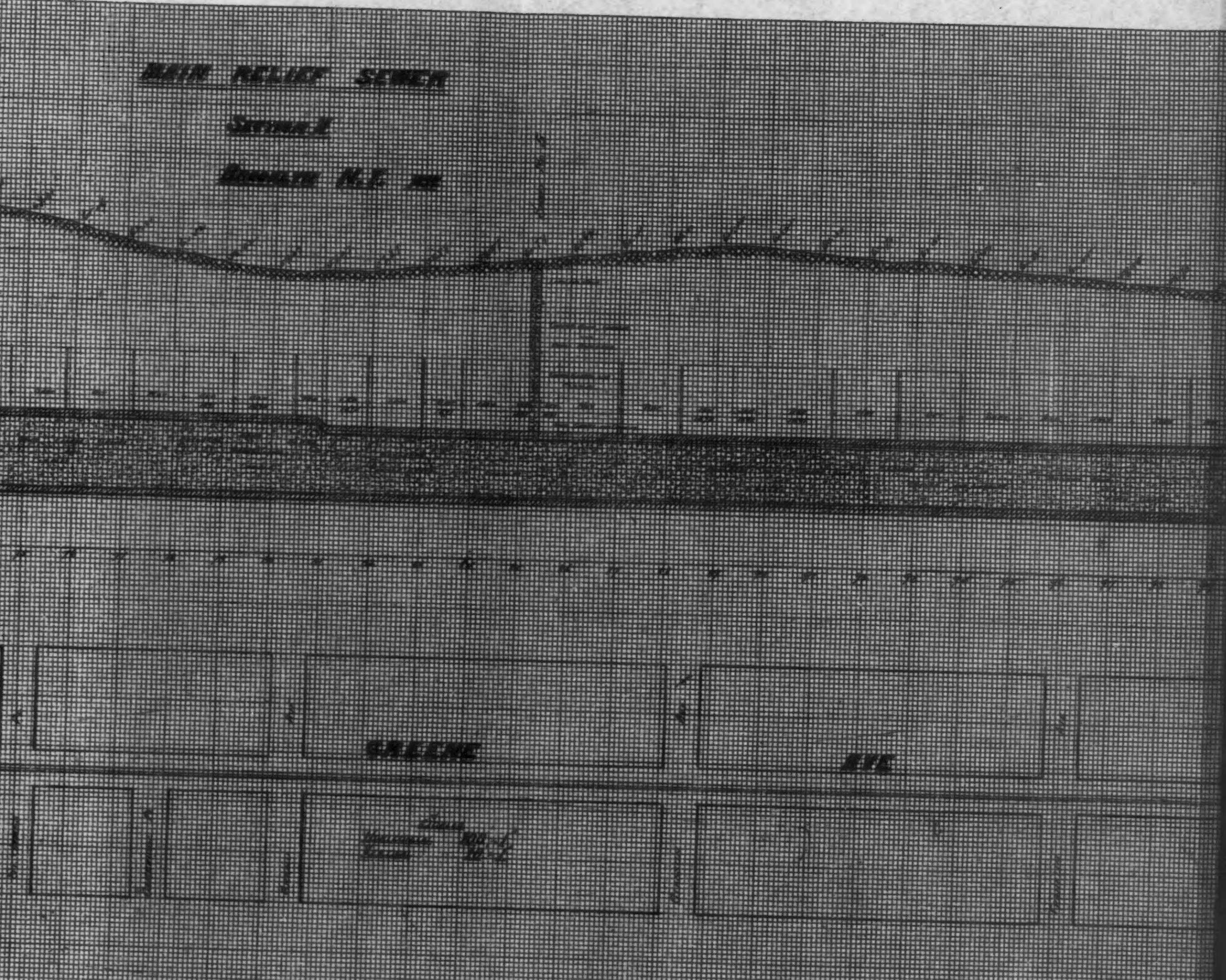











MAIN RELIEF SEWER
GREENE
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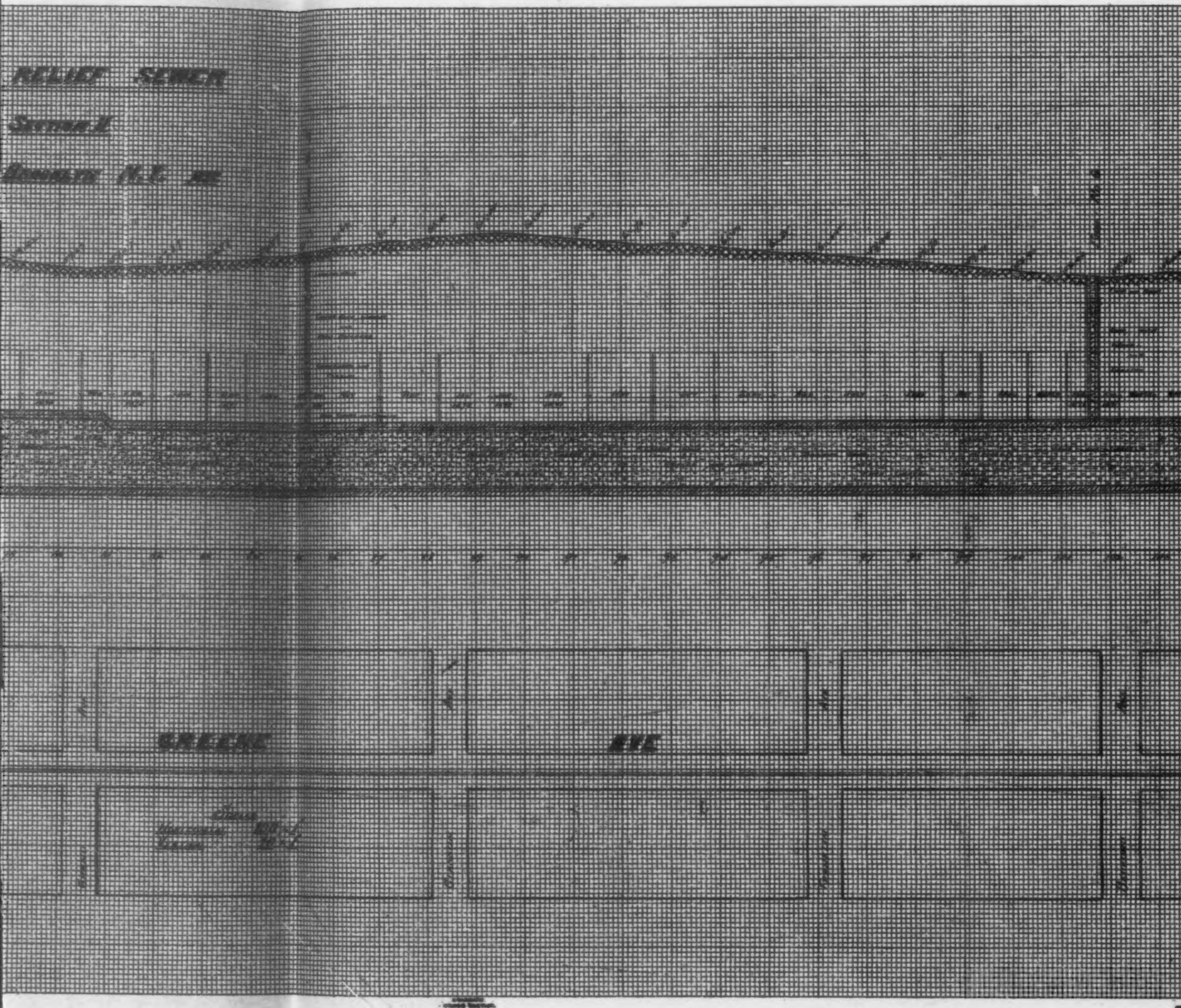
RELIEF SEWER
GREENE
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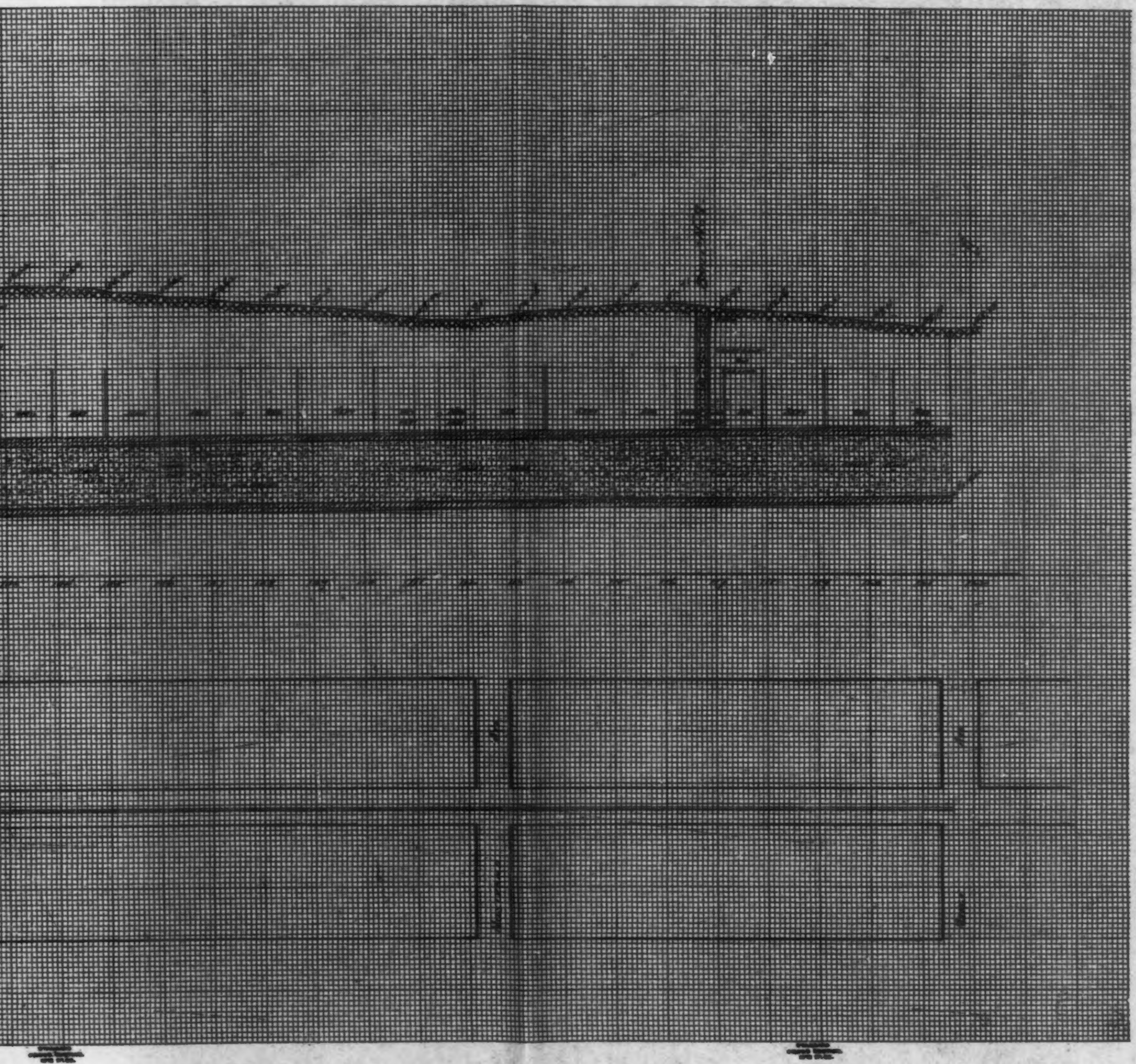
PLATE XLIV.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXVI. Nº 529.
BEAHAN ON
BROOKLYN RELIEF SEWER.



sewers are of brick or stone. In the recent rapid growth of the city, those in the old residence district of Brooklyn Heights needed to be supplemented. Much of the new residence district is found in Sewer Districts "F," "K" and "L," whose main sewers became surcharged in storms. To relieve all of District "F" and the portions of Districts "K" and "L" lying south of Greene Avenue is the object of the Main Relief Sewer of which we speak. The accompanying map clearly shows the situation (Plate XLII).

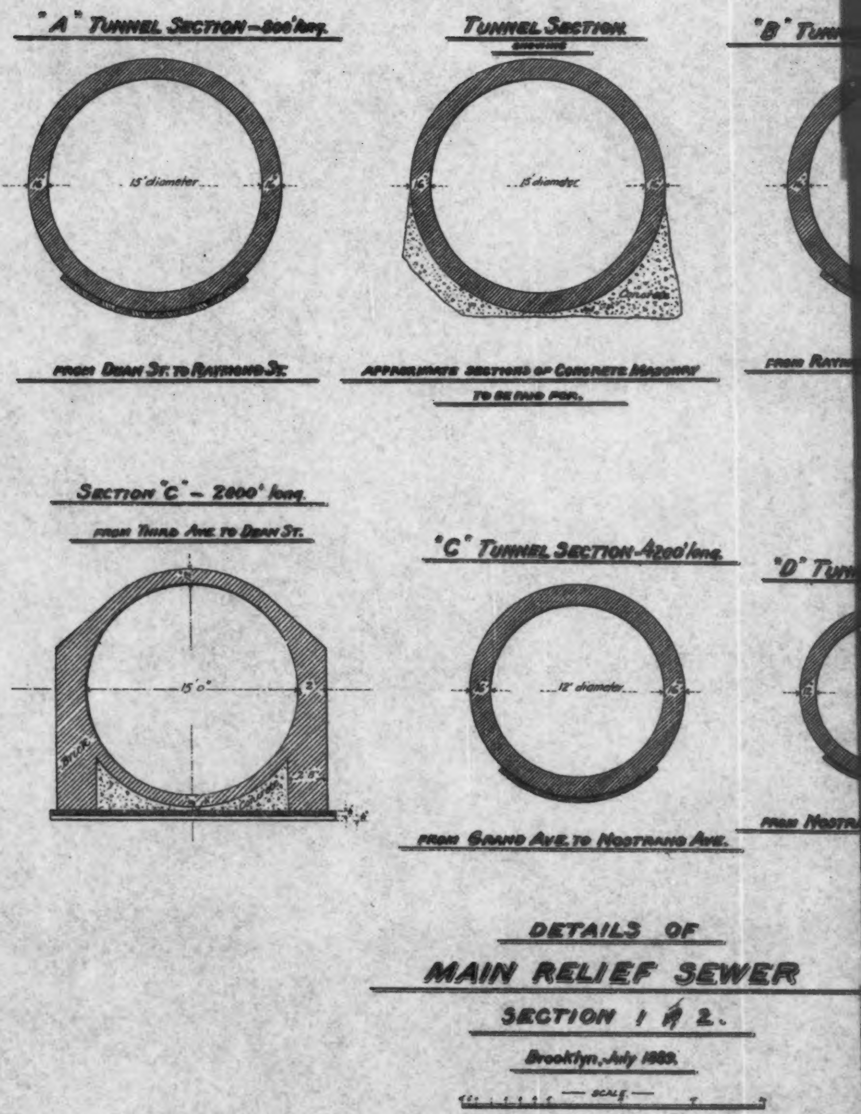
For the outlet of the new sewer, it was decided to use the Gowanus Canal, this giving the shortest egress to tide-water. As it was to carry excess water in storms, its outflow would improve rather than injure the condition of the canal. Starting, then, at the head of the Gowanus Canal, near Butler Street, at a point between Nevins Street and Bond Street, the first district main to be relieved is the Raymond Street main, at the foot of Hanson Place, this conveying all of the drainage of District "F." The next is the Grand Avenue main, intercepted at Grand and Greene Avenues, and there charged with the sewage of the part of District "K" which lies south of Greene Avenue. The portion of District "L" lying south of Greene Avenue is relieved at three points on Greene Avenue, viz., Bedford, Nostrand and Marcy Avenues. At Marcy Avenue is the present terminus of the Main Relief Sewer; its location is shown on the map, and its length is 12 300 feet.

The drainage area, the sewers of which are intercepted, is 2 000 acres. The flood water of storms was that for which provision was to be made, and the house drainage was to be allowed to flow by in the present mains. It was deemed safe to provide for the storm water from an area of 1 300 acres. The maximum rainfall in Brooklyn is 4 inches per hour, and of this it was assumed that 1 inch per hour would reach the Relief Sewer. The bottom of the invert at Gowanus Canal was fixed at the elevation of mean high water for that place, thus establishing the grade elevation at the outlet. At Nostrand Avenue on Greene Avenue, it will be noticed that the profile (Plates XLIII and XLIV) shows low ground, and the bottom of the brickwork of the Nostrand Avenue main sewer, where it crossed Greene Avenue, was a point the elevation of which controlled the maximum elevation allowable for the top of the brickwork of the Main Relief Sewer, thus giving a second controlling point in the grade line. The level of the ground water for the city as caused by rains and held by

impervious ground is at an elevation of about 11 feet above high tide. Strictly speaking, this water level is an inclined plane, and fluctuates at times, rising at occasional points in a way not readily accounted for. To lay a sewer grade-line so that the bottom of the excavation passes below this plane, necessitates ceaseless pumping.

The elevation of this water at different points along the line of the sewer was next determined by boring; the character of the material to be met with on the line of the sewer being determined at the same time. At the Department of City Works of Brooklyn the results of borings are given but little credence. The writer inclines to the opinion that the little that can be done in boring is a small fraction of what we assume ourselves able to do. The complete record of the gross errors of conclusion made from borings, would stagger any man. On Long Island a couple of men had been seen digging wells for farmers in a way that seemed to be adapted to the problem in hand. They were employed to sink test shafts 4 feet square on the center line of the proposed sewer to and below the proposed sewer sections, using four horizontal boards in a rectangle, notched and pinned together at the corners. They thus built, as did the Irishman his chimney—"from the top downward," to the water surface. Notes of the material were kept as they progressed, and the distance to water surface noted; the material met was the drift on which Brooklyn is built, consisting for the most part of sand and gravel. The sand was sometimes dry and fine, but usually damp enough to stand well. The gravel was of all possible sorts; it was cemented together in some places, and in a few instances was a mass of cobble stones with no intermixed material. Clay or hard pan was met on Hanson Place. Heavy granite boulders were found sometimes in the clay, sometimes in sand or gravel, but always in passing into or away from the clay. These boulders, as it was subsequently found, ranged from the size of a cobble stone to those containing 10 cubic yards. In sinking the shaft at St. Felix Street and Hanson Place, a water pocket was met in the sand, necessitating tight curbing for some 12 feet. Clay underlaid this water, and probably a depression in the upper surface of this clay stratum caused the water to collect there. The bottom of the pocket was nearly as low as the top of the proposed brickwork.

The form of section chosen for the sewer was a circle, except where the head room was insufficient for such a section, as this is the strongest



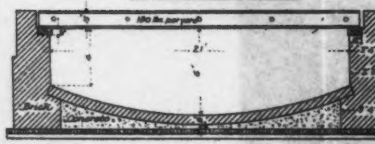
"A" TUNNEL SECTION—800' long.
15' diameter
FROM DEAN ST. TO RAYMOND ST.
TUNNEL SECTION
SHOWING
15' diameter
Concrete
APPROXIMATE SECTIONS OF CONCRETE MASONRY
TO BE PAID FOR.
"B" TUNN
FROM RAYM
SECTION "C" – 2800' long.
FROM THIRD AVE. TO DEAN ST.
15' 0"
Brick
Concrete
"C" TUNNEL SECTION-4200' long.
12' diameter
FROM GRAND AVE. TO NOSTRAND AVE.
"D" TUNN
FROM NOSTRA
DETAILS OF
MAIN RELIEF SEWER
SECTION 1 & 2.
Brooklyn, July 1889.
SCALE

"B" TUNNEL SECTION - 4400' long.

FROM RAYMOND ST. TO GRAND AVE.

NEXT TO

CROSS SECTION.

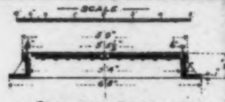


CROSS SECTION.

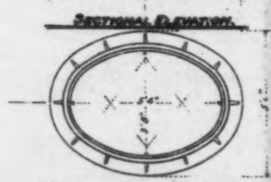
"D" TUNNEL SECTION.

FROM NOSTRAND AVE. TO MARCY AVE.

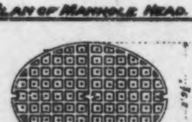
PLANS FOR MANHOLE HEADS AND COVERS.



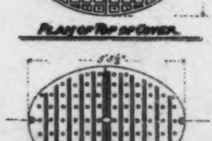
SECTIONAL ELEVATION.



PLAN OF MANHOLE HEAD.



PLAN OF TOP OF COVER.



PLAN OF BOTTOM OF COVER.

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PLATE XLV
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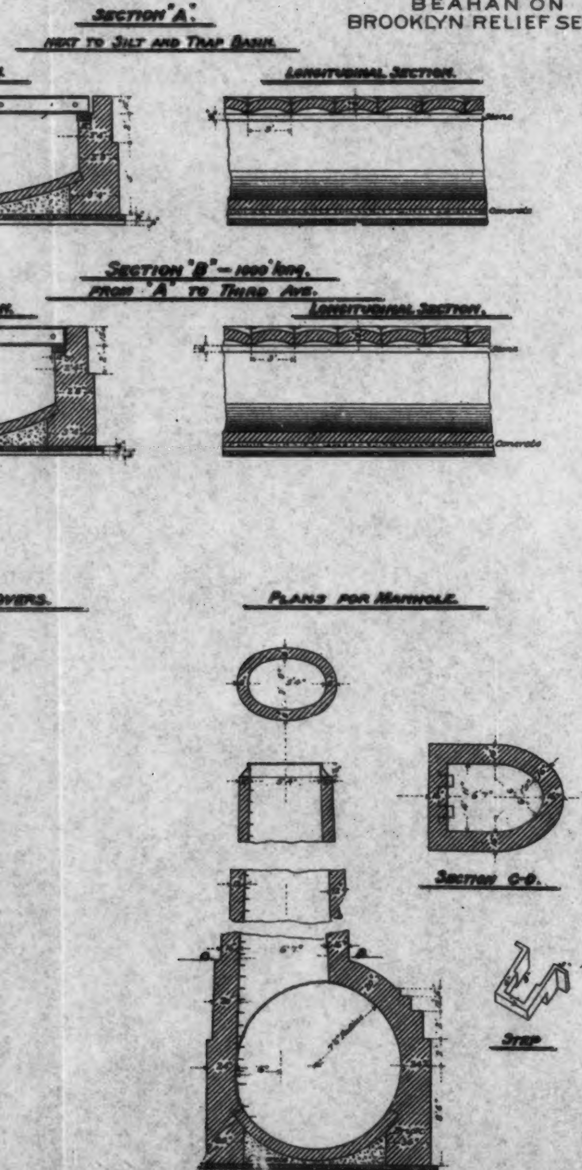

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section for loose material and the section of least resistance to the full flow. The only change from this form was at the outlet on Butler Street, where there was insufficient head room, and I-beams were required; on this account the gradient on this street was increased, since the reduced section required it. The grade line as adopted is shown on the profile.

After construction had begun, owing to excessive storms, or the fact of a layer of quicksand at Shaft No. 3, the water there was found to be higher than the test shafts had shown, and the pumps removed the sand with the water. The grade line was raised to correspond with the water surface as found, although some pumping was required while laying the bottom courses of brick, for a long way from this shaft. The author does not seek to explain this change in water level. It is now plain that to raise the grade line was the only practicable solution.

Of the entire drainage area, 2 000 acres, of the three sewer districts relieved but 1 300 acres would ever empty storm water into the sewer to be built, on which let us take, as stated, the maximum rainfall per hour as 4 inches, of which 1 inch per hour reaches the sewer as a maximum. By Kutter's formula, $Q = av$ where $v = c\sqrt{rs}$. Determining c for a coefficient n in the formula $= .015$ for brick, and using a fall of 1 in 1 000, we get for a circular sewer 15 feet in diameter $v = 237.9 \times .031623 = 7.52$. $\therefore$ $Q = 176.72 \times 7.52 = 1325.4$ cubic feet per second for the maximum discharge. One inch per hour on 1 300 acres is 1 313 cubic feet per second. Fifteen feet is the diameter employed below where the Raymond Street sewer enters, and the gradient is somewhat steeper than 1 in 1 000 over that section.

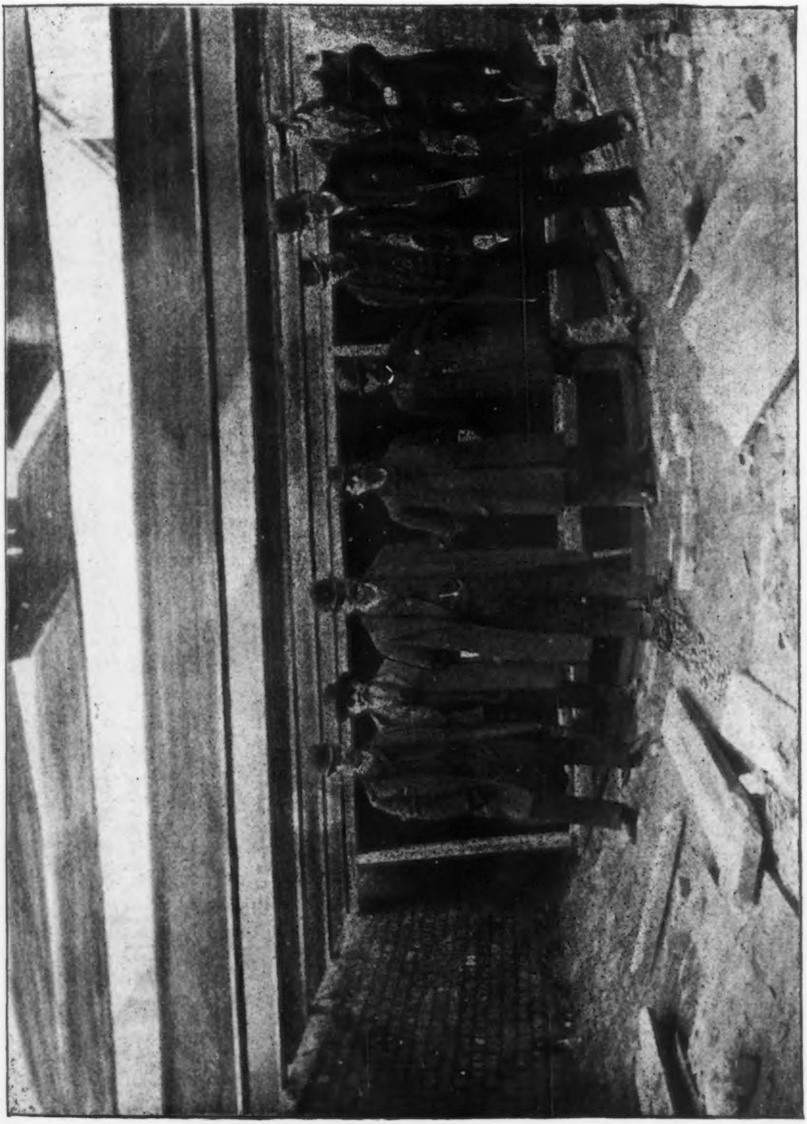
The general structure of the sewer is briefly described thus (Plate XLV): Starting at its upper end on Greene Avenue, beyond Marcy Avenue, we have a circular brick sewer 10 feet in diameter, and at Marcy Avenue one of 12 feet in diameter. At Marcy, Nostrand and Bedford Avenues, the sewers of District "L" are intercepted. Just before reaching Grand Avenue the diameter increases to 14 feet, and at Grand Avenue the main sewer of District "K" is relieved. At Raymond Street and Hanson Place the diameter of the sewer is increased to 15 feet, and the main from District "F" relieved. Just after leaving Fourth Avenue and turning down Butler Street, the head room is insufficient for a circular sewer of such diameter, and a segmental invert, verti-

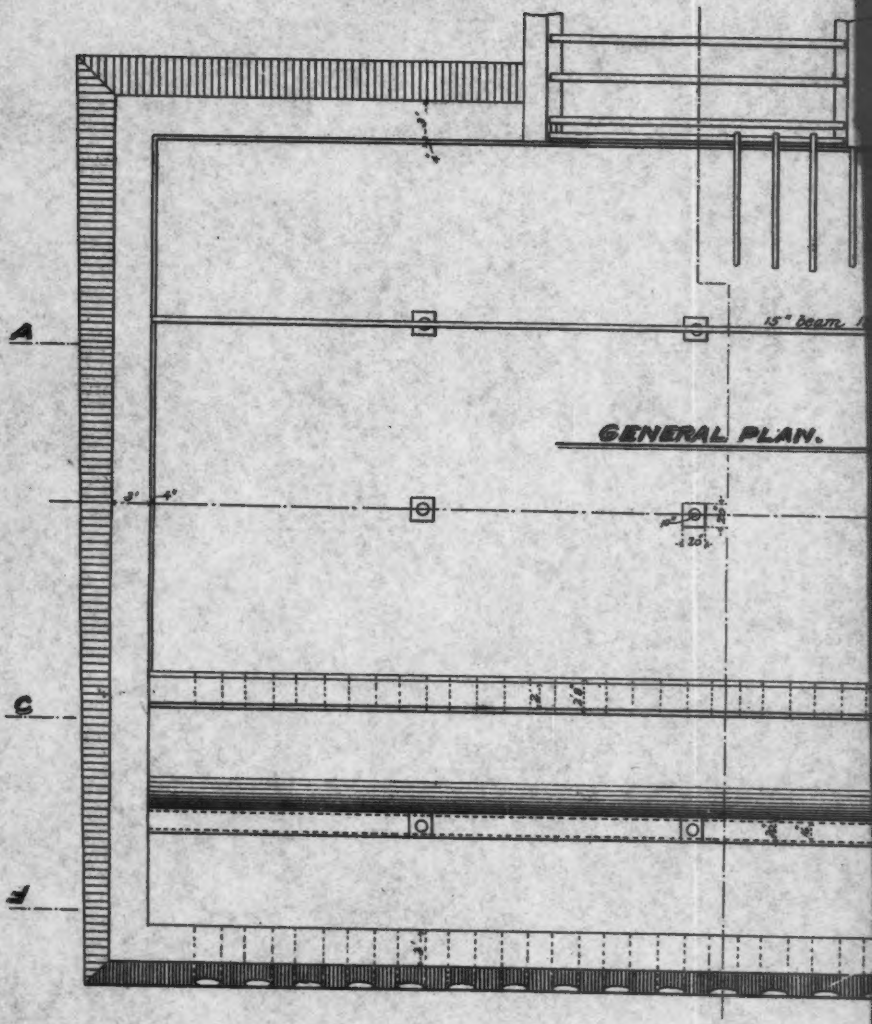
cal side walls and a flat top composed of I-beams (Plate XLVI), with flat brick arches to fill spaces between these beams and carry the street surface, are employed. Finally, we have the large trap basin with all its appurtenances, at tide water at the canal.

The estimate of cost was, at the first, $1 000 000. The actual cost was kept within that estimate.

The method of construction was the next thing to be decided. At Vanderbilt Avenue the depth from the surface of the street to the bottom of the invert was 90 feet. For a great part of the way the average depth exceeded 50 feet. Clearly, this portion had to be tunneled. Where the sewer entered the Gowanus Canal the cutting was shallow, and continued so to Fourth Avenue. It was decided, therefore, to build the sewer in open cut 2 940 feet from the canal to Dean Street, and to tunnel for the remainder of the distance. The open cut work was designated Section No. 1, and on July 1st, 1890, the contract for it was awarded to Daniel J. Creem, Brooklyn, two hundred working days being given in which to complete the work. The tunnel portion of the work 9 340 feet in total length was designated Section No. 2, and on June 27th, 1890, the contract was awarded to Charles Hart, Fourth Avenue and DeGraw Street, Brooklyn, and Anderson & Barr, of No. 240 Eleventh Avenue, Jersey City, under the firm name of Hart, Anderson & Barr, and three hundred working days named as the time within which work was to be finished. There was no stipulation as to the method of tunneling. Work on each section was begun at once, and was completed by the parties named, Section No. 1 being finished in December, 1891, and Section No. 2 in February, 1892.

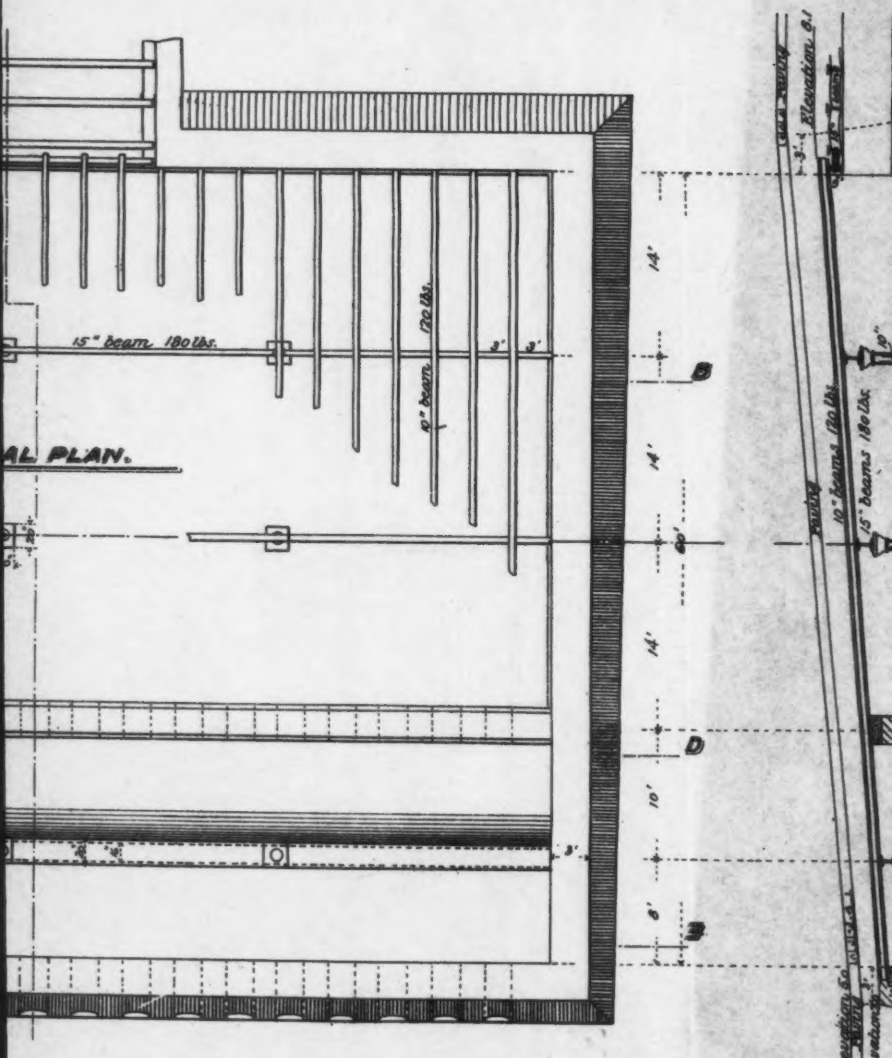
In constructing Section No. 1, sheeting and timbering were used in the ordinary manner for open cut work. The material excavated was lifted by derrick and bucket to cars on a track running alongside the work. The cars were hauled by horses back to where the brickwork was completed, and there dumped. Work was begun at the lower end and carried forward as described. No difficulties occurred, save the falling of a small portion of the arch where the section was changing from circular to flat topped. This it was thought arose either from striking the centers before giving all the time needed for the cement to set, or from a slight yielding of the upper portion of the trench walls. The trap basin formed no small part of the work of Section No. 1. Its construction is most instructive and is shown on plans





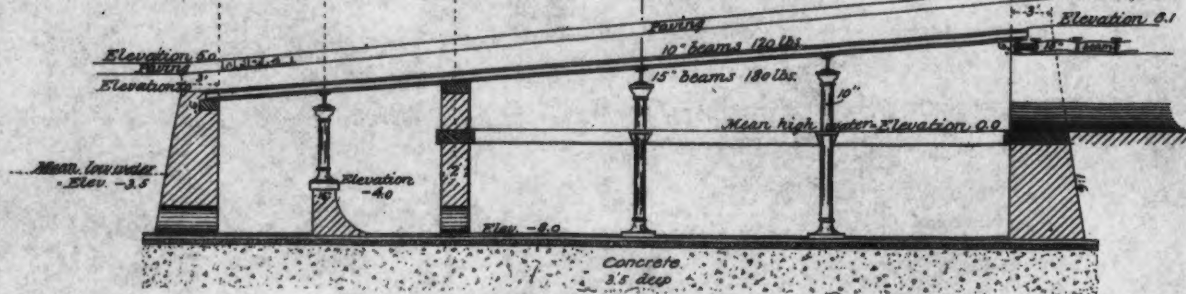
SILT TRAP BAS

Scale.

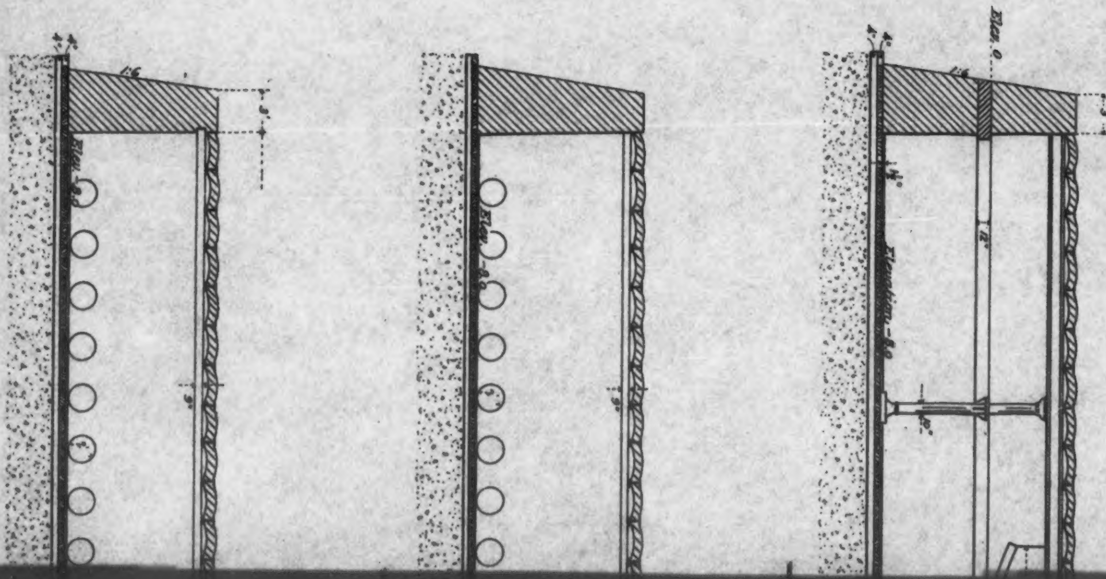


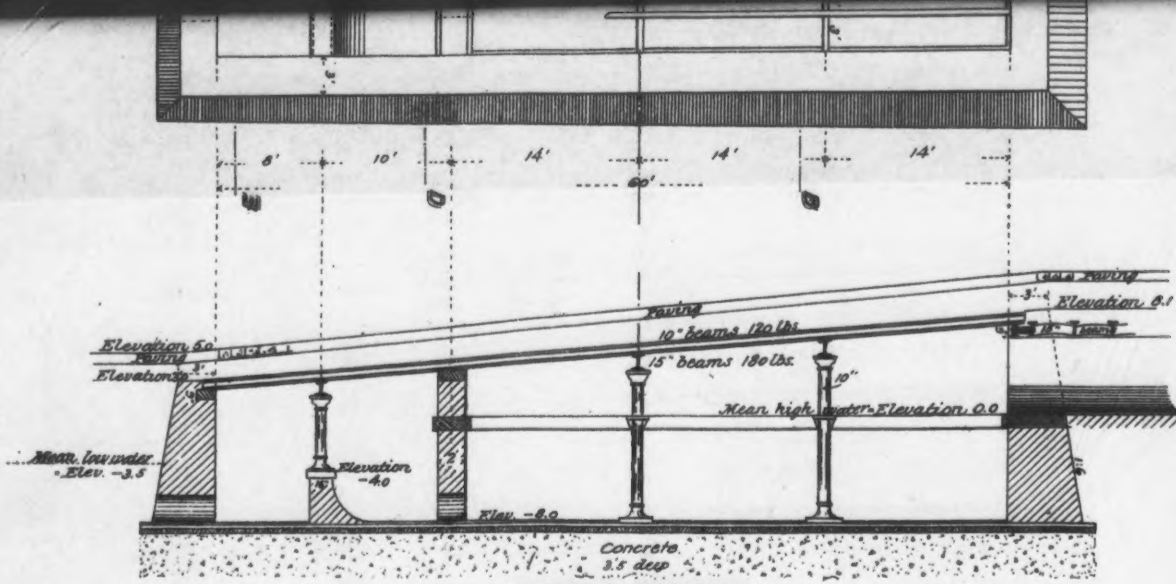
TRAP BASIN.

Scale.



CROSS SECTION.





CROSS SECTION.

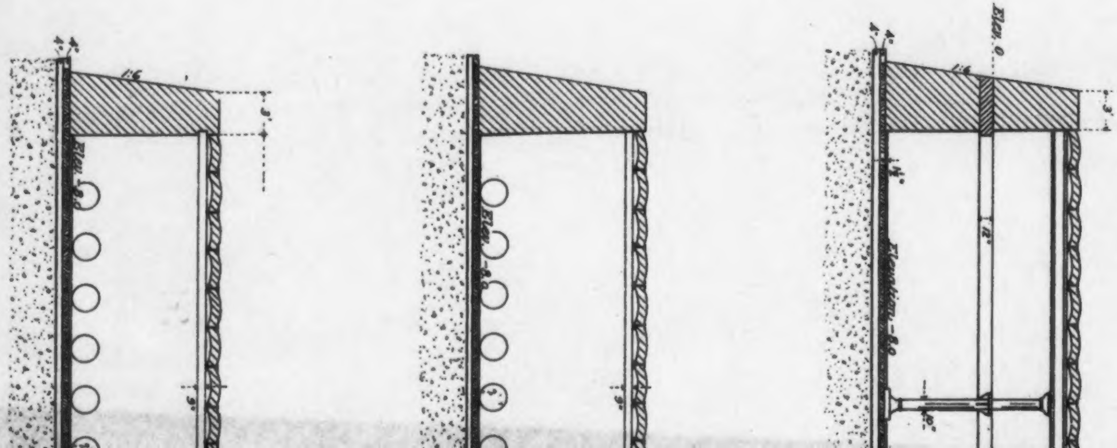


PLATE XLVII.
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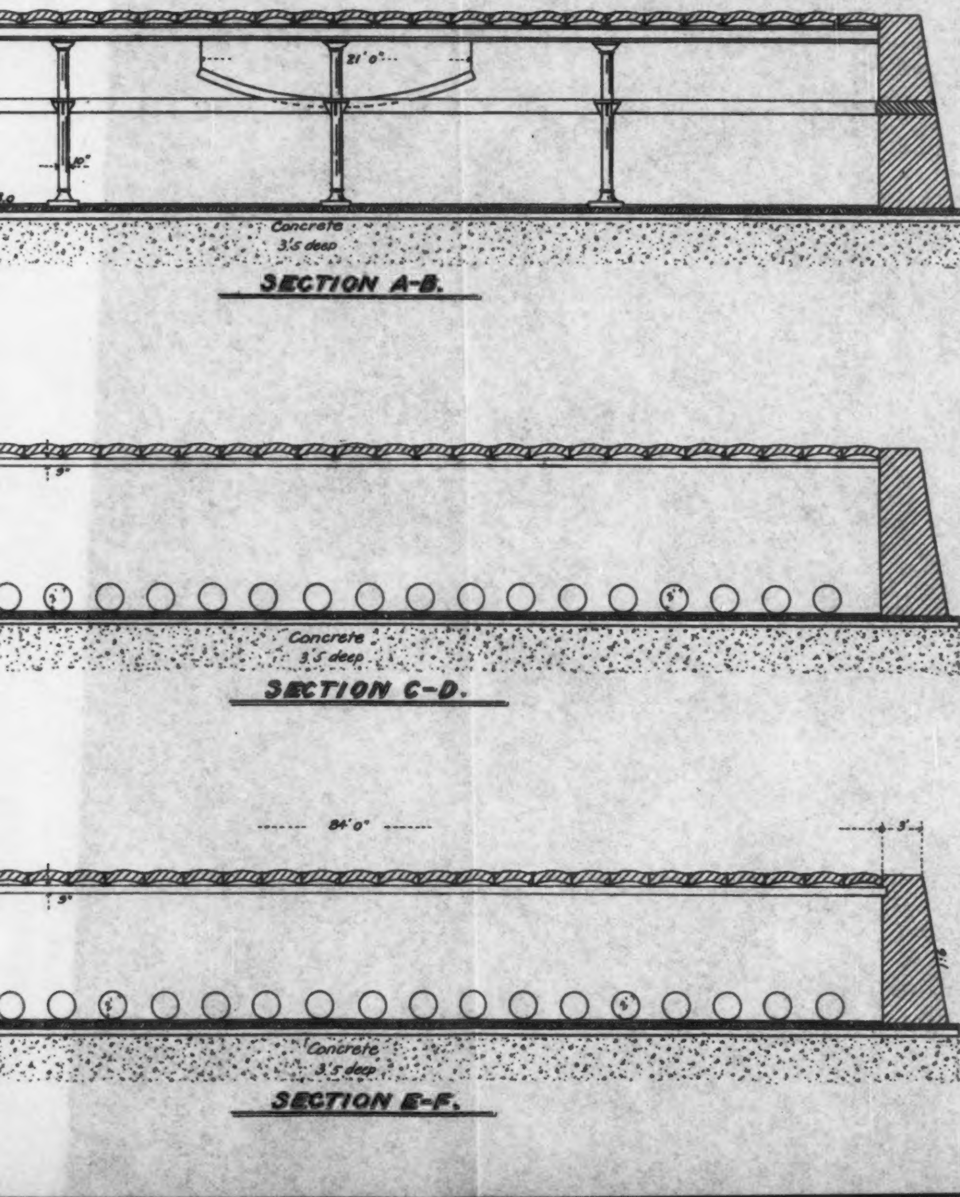


herewith (Plate XLVII). No difficulties were met in carrying out the designs. The special features of plan and detail, as well as the sewer as a whole, will be treated of later.

The depth of Section No. 2 varied from a least depth at Dean Street of 37 feet, to a greatest depth of 90 feet at Vanderbilt Avenue. The diameter of the sewer inside the brickwork was to be, starting at Dean Street, 15 feet for 700 feet, 14 feet for 4 700 feet more, and then 12 feet to Marcy Avenue. The route lay along paved streets, asphalt or stone all the way, and under horse-car tracks and a cement pipe sewer for much of the way. It was a populous residence district, with its usual complement of gas, water and sewer pipes. The residences were usually three-story brick buildings with stone fronts. The Brooklyn Tabernacle and many other churches, with heavy spires close to the sidewalk, were on the route. The lines of three elevated roads were also to be passed under.

The material, as shown in the test shafts, was the drift already described. This work comes, therefore, under the general case of tunnels of medium cross-section in ordinary soft ground, and is a fair basis for the discussion of methods for tunneling in such material; herein lies its interest to engineers. In these days of rapid transit, of provisions for larger drainage or increased water supply, and of increased restrictions placed upon the bridging of navigable streams, the question of tunnel systems is one of interest to us. Any current newspaper clamoring for rapid underground transit sagely mentions a shield as the *summum bonum* of tunneldom. Any railroad engineer thwarted by the War Department in an attempted bridge over navigable waters seeks the shelter of a shield, for he has heard of a shield being used at the Sarnia or St. Clair tunnel to aid in such an extremity as the one he is in. To him it seems a veritable "Hobson's choice." If a tunnel cannot or will not be built best by the use of a shield, it is all the fault of the tunnel, he thinks. We all use and resort to that which is before our eyes, and tunneling in soft ground is not frequent enough in its examples to allow us to make the distinctions which circumstances would dictate on closer study. There is no one method for tunneling in such ground that is the best. The size of the cross section of the tunnel, the kind of ground to be tunneled through, and the surroundings are considerations that must rule in planning how to do the work. A method of tunneling well adapted to a tunnel 28 feet in

diameter is quite apt to be less adapted to a tunnel of half that diameter. Again, a method of tunneling practicable in a putty-like clay under a river, is not necessarily best among huge boulders. The author is aware of the outcry that will be made against this, to him, sound reasoning, but he has read tunnel literature in newspapers and engineering journals, and visited tunnels under construction; talked with tunnel men, and heard the praises of "tunnel systems" sung, until he feels called upon to say that common sense applies even to expert tunneling. The best method to use in building a certain tunnel is that which costs the least to do the desired work.

There are to-day three general and distinct methods of tunneling in soft ground. The first in the order of introduction is the timbered system. It embraces several distinct types and many modifications or mergings of them. The English, Austrian, German and Belgian are the principal ones.

In Pennsylvania and in the South, the German method of segmental timbering with a supporting core, and the English bar method, are used.

Tunneling was begun in that way for railroads, usually not in sand, but in clay. A combination of the English and German methods is in use in trying circumstances by the Baltimore and Ohio Railroad, for their double-track belt line in Baltimore, and is fairly successful, but the Brooklyn tunnel was much smaller and poorly adapted for its use. Those methods are never inexpensive or rapid. The German, with its core of soft ground, is dangerous to the arch, and makes the side-wall construction difficult. Timber is more expensive than in former times, and any timber exceeding in length two-thirds of the finished diameter of the tunnel section is difficult and expensive to handle. To draw the crown timbers from the top of an arch in the English method is never desirable, and requires a great pulling force when the material driven through is dry sand, boulders or gravel. In the streets of Brooklyn, to draw them would cause a settlement sufficient to break pipe sewers and water pipes above, and would damage pavements. If left in, there is still considerable space to be filled with earth by ramming, and horizontal ramming is never satisfactory in irregular spaces, especially in such material. For these reasons it was concluded that timbering in so small a section would be cumbersome and slow, and was not a desirable method.

The second system, in which a shield is used, was then considered. A shield calls for a large initial outlay and a considerable addition to the cost of operating machinery during the progress of a work. This method was first used by Brunel in the stiff London clay, and, later, was improved and further used by Greathead. A simpler form was designed by Beach and patented in 1869 in this country.

Recently, we have been using shields of better models than those of Brunel, but of the same type in all essentials, and we all must recognize his originality and boldness. Greathead and others have improved it, if we take the old shield as shown in "Drinker on Tunneling," as an illustration. Mr. Beach's shield as patented would not be recognizable as a shield at Sarnia. But the writer is not aware of any patents in force, and the pseudo-wisdom and exclusive knowledge some of us profess in this matter is most ill-timed. Is not a shield essentially a pneumatic appliance? Shields, like cantilever bridges, are perhaps imperative under certain circumstances. A few years ago we thought we must use a cantilever, where now we see we could use less expensive types better. So of shields in tunneling—we talk shield now as we have been talking cantilever. The author thinks no material is fit to use a shield in, unless that material will flow. Under water, where air pressure is needed, a shield protects. If the material is soft, as in the Hudson River Tunnel, a shield increases the safety of the men, and is a good system, but not an indispensable one. The latter is the most rational place in which to use a shield the author ever saw or heard of, and Mr. Moier did rapid work there last year by its use, and demonstrated its efficiency. At the St. Clair Tunnel there was little use for shields, as the clay generally could have been tunneled by any system that could stand the shearing stress, for it would not fall or flow and was air and water tight. Where they met the water-bearing pocket of sandy material, the shield gave considerable aid. Usually, the excavating was done by the men in front of the shield and the muck passed out through the doors—an expensive process. The shield was then shoved forward, shaving off the ragged edges of the cut to the neat lines. This seems a sentimental use of Brunel's invention as compared with the Hudson River Tunnel work.

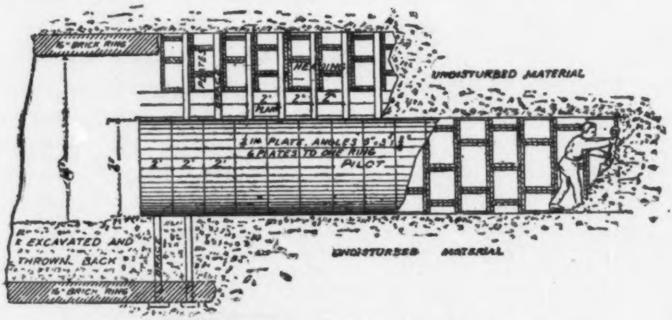
Several years ago, Hart, Anderson & Barr built and used a shield in the Knickerbocker Avenue extension sewer on South Fifth Street,

Brooklyn. The material was presumably the same as for the work now to be done. It was found on trial that the shield was difficult to keep up to grade line, and made smooth brickwork impossible. It was also found that even in fine sand no amount of pressure would make that sand flow through the doors. The men were obliged to go through the doors, pole away the sand from before the cutting edges of the shield, and shovel it out through the doors before the shield could possibly be shoved forward. Had the material been dry instead of damp sand that stood well, the shield could never have been moved at all. The material would have taken such a slope, that to relieve the cutting edges around the bottom of the shield, would necessitate removing material enough to cause the sand to come down in front of the cutting edge at the roof of the shield, thereby causing a settlement of the surface of the street. As it was expected that some boulders would be met, the outlook for using this shield on South Fifth Street was discouraging. A large boulder squarely across the cutting edge in the front of the bottom of the shield would stop it effectually, and after working it for some time and making very slow progress, the shield was abandoned and bricked in.

The third and last system of tunneling in soft ground, called the pilot system, was introduced in 1880 by Anderson, who was then superintendent of the Hudson River Tunnel. It consists primarily of a small tunnel advanced by the poling process ahead of the full-sized section, and this smaller circular tunnel is lined completely with steel plates bolted together. By poling, the roof and then the sides and invert of the full section are excavated from around this pilot, and the braces supporting the roof rest on the pilot. This pilot or exploration tunnel had originally for its purpose the finding out of dangerous ground ahead. As it is carried in the center of the section it reduces the length of all braces, so that nothing but small, short timbers are needed. These braces are therefore but a small part of the cost of the shoring necessary for a timbered construction, and no crown pieces are needed. The brickwork is built out to the lining or sheeting all the way around the section, thus doing away with tamping and settling. Smaller timbers and no voids are the features of this method as against the timbered plans of work.

The comparative cost of these three methods for the case in hand is the next question. The cost of a timbered section and its advantages

have already been sufficiently stated. The cost of using the shield system needs more consideration. The shields for the St. Clair Tunnel weighed 85 tons each. They were of the best quality of steel, and, of course, the patterns were quite expensive. Except where there are few headings this initial cost is quite prohibitive. By the time the shield is built and at the bottom of the shaft or tunnel portal, with its complement of jacks and machinery, no small percentage of the expected profits has been expended on an ordinary tunnel contract. But the greatest outlay has still to be met, that is, the cast iron lining which so far has always been found to be required. Mr.



LONGITUDINAL SECTION. MAIN RELIEF SEWER—IN TUNNEL.

FIG. 1.

Hobson used twenty-four hydraulic jacks at St. Clair with each shield, each jack having a capacity of 125 tons. These jacks need something strong to stand their back thrust. Brickwork will not stand such compression by any means now known. Nothing else than a cast-iron lining has served thus far here. At St. Clair this lining was 2 inches thick and heavily flanged. At the Hudson River Tunnel they used thinner plates for a time, but were later obliged to make them heavier —of the 2-inch thickness, I believe. The cost of such cast-iron lining alone, about equals the cost of a brick-lined tunnel of the same diameter. So long as this be true, shields will be used by corporations rather than by contractors, for they cannot compete in price with the other ways of doing the work.

Inasmuch as the pilot system would avoid the settlement of the streets and be less cumbersome in the section to be built than a tim-

bered system of doing the Brooklyn work, it was considered preferable; and, inasmuch as the pilot system would contend with boulders successfully and this material would not flow, the pilot was thought better than the shield. The pilot system was therefore used.

The method of work pursued on Section No. 1, the open cut, has already been spoken of. Work was begun at the trap basin at Gowanus Canal and carried forward by derrick, bucket, and track for cars alongside the cut. Surface pipes were shifted, or slung, or troughs carried in their stead. On Fourth Avenue, the line of the sewer being on one side of the street, and the cutting exceeding 25 feet, the sheeting would yield enough to disturb the curb and sidewalks slightly, and it caused a few doors of buildings to show disturbance. The sheeting was 2-inch plank, driven by hand, and held by 6 x 8-inch rangers and braces, in the usual way. Interruptions of the work by rains increased the loss of this sandy material through cracks in sheeting and around ends of planking. Section No. 1 was completed expeditiously. It had a maximum cutting of 36 feet at Dean Street, where it joined with Section No. 2. The method of timbering the cut, the height to which the invert was carried before centering was put up, the centers and the arch, are shown in Plate XLVIII.

On the tunnel section, some other way than commencing at one end and working toward the other had to be adopted. A tunnel on comparatively level ground must be attacked differently from a tunnel through a mountain or under water. To do the work most economically there must be more points of attack. The distance the shafts should be apart is determinate, and depends upon the depths and consequent cost of the shaft, and the cost of transportation of muck and material. On the profile the shaft locations as numbered are shown. On this work the cars were pushed by men, and there was necessarily one passing switch in the tunnel near the shaft and another near the heading. When there was time, after putting a loaded car on the cage, to take an empty car from the siding at the shaft and put it on the siding at the heading before the last empty car taken from there could be shoveled full, the distance from the heading to the shaft was not too great for economy. Otherwise, a middle siding would have had to be used, and the pay-roll would have been increased without any increase in the amount of muck sent out. This limit of distance was about 800 feet, but good muck to shovel would decrease it. This gave, then, 1 600 feet between the shafts as the economic distance.

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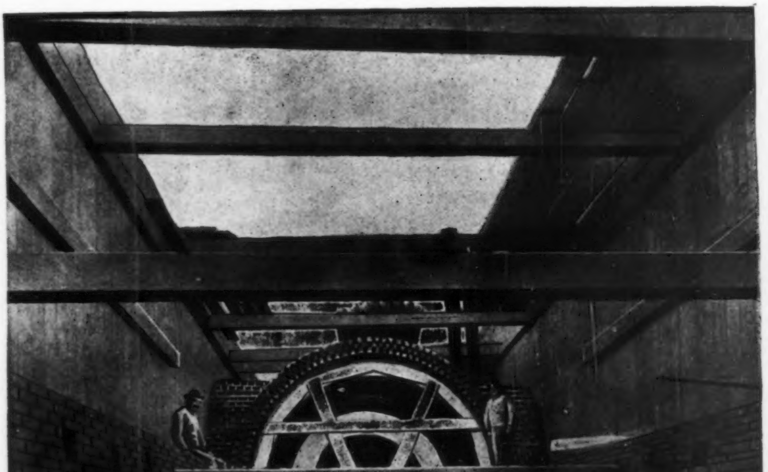

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In crowded city streets there are other considerations than economy for the contractor, and manhole locations are to be taken into account in deep work. The variations from the distance named and the reasons for it are not essential here. The shafts were sunk over the tunnel in all cases, and exactly on the center line, save where street-car tracks prevented. They were of rectangular section, about 18 x 24 feet on top. The greater length was along the axis of the sewer, so as to give greater length of base line for prolonging the center line into the headings with the transit and plumb bobs. Two-inch sheeting, 13 feet long, and driven by hand was used. Rangers 6 x 8 inches were placed in three sets on each sheeting length. Two braces were put in, and in loose ground these were made double. Two cross-braces were put in and completed the set, and the space for the cage was formed within the inner braces. The guides to the cage and all top work at a shaft are as shown in the cut from a photograph at Shaft No. 3 (Plate XLIX). The cage was a wooden platform with a tram-car track across it. The muck was loaded into cars, pushed by men to and upon the cage, and securely blocked. The cage, with the car, was hoisted up to the trestle track, and the car pushed out on the trestle and dumped sidewise on screens of such mesh and set at such angle as to let the sand through the screen under the trestle, and carry the gravel across the screen to one side of the trestle, all without labor.

The brick, when needed, was loaded into these cars from the lower track on the street, placed on the cage, lowered down, pushed to the heading and dumped—there to be passed to the bricklayers.

The cars were made by the C. W. Hunt Co., and proved durable. On reasonably good track they were seldom derailed, but they are too wide on top for a tunnel car, and flaring sides are not desirable. In dumping brick or other material from them on a surface level with the track, one-third remains in the car and must be taken out by hand. A car should dump its entire load and get out of the way speedily. In taking out muck, the gravel stones, if not cleaned away with the fingers from the rails, would block a car loaded with one cubic yard so that five men could not stir it. Larger wheels would avoid this. A special pattern designed with these facts in mind could surely be made which would still retain the desirable features of the present car, which is the best now in the market.

The shaft sunk, the pilot is next to be started. We have seen that

the pilot is cylindrical, usually about 6 feet in diameter, with rings 2 feet long, each ring consisting of six plates of equal length; all fastened together with bolts. The plates are of steel, with inside flanges riveted on them; the weight of metal and method of construction depend on the material to be met; they are used repeatedly, and enough for 40 feet of pilot is needed for a heading. The first two rings are set up in the shaft—blocking them up to center and grade lines. The sheeting is then bored through on the line of the pilot ring, cutting out the plank and rangers piece by piece, and working in the iron poling boards like those shown in the cut of heading work. These iron poling boards are carried down 2 feet from the center. A half plate is then put in, *i. e.*, a plate made half width for ease in holding up while bolting. We next pole down on either side, using a wooden poling board, to the center of the sides of the pilot and put a half plate on each side. Now, go back and put another half plate in the roof and again fill out the sides, bulkhead up the front face, and put in the three full bottom plates. This completes a ring, and is the entire process of driving a pilot—barring difficulties. The next ring is put ahead in like manner except that the first roof plate instead of being in the center has one end at the center. The horizontal joints of one ring are thus put in the center of the plates of the adjacent rings. The tools used are much the same as those shown in the heading work.

One man and a helper will keep the pilot sufficiently advanced; it should be kept on the center line for direction, and carried for grade at the right distance below the roof to allow the center heading man to stand upon the pilot and conveniently put in his heading plates. The pilot is guided by wooden wedges, the method of use and limits of efficiency of which are not pertinent here. When one pilot is a few rings inside the sheeting, the other may be started. A pilot being well under way, the heading is started over it by marking out the circle of the outer line of the brickwork on the sheeting, and boring the sheeting so as to take it out in small pieces. The heading plates are then bolted together in two rings and set up in the shaft; iron poling boards are brought into requisition, and the roof is worked ahead by the various and varying means and ways which experience alone can teach. The material just outside the sheeting is always loose, as it has been shaken in sinking the shaft. To start the work from a shaft without losing material, always requires care and

PLATE XLIX.
TRANS. AM. SOC. CIV. ENGS.
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BEAHAN ON BROOKLYN RELIEF SEWER.

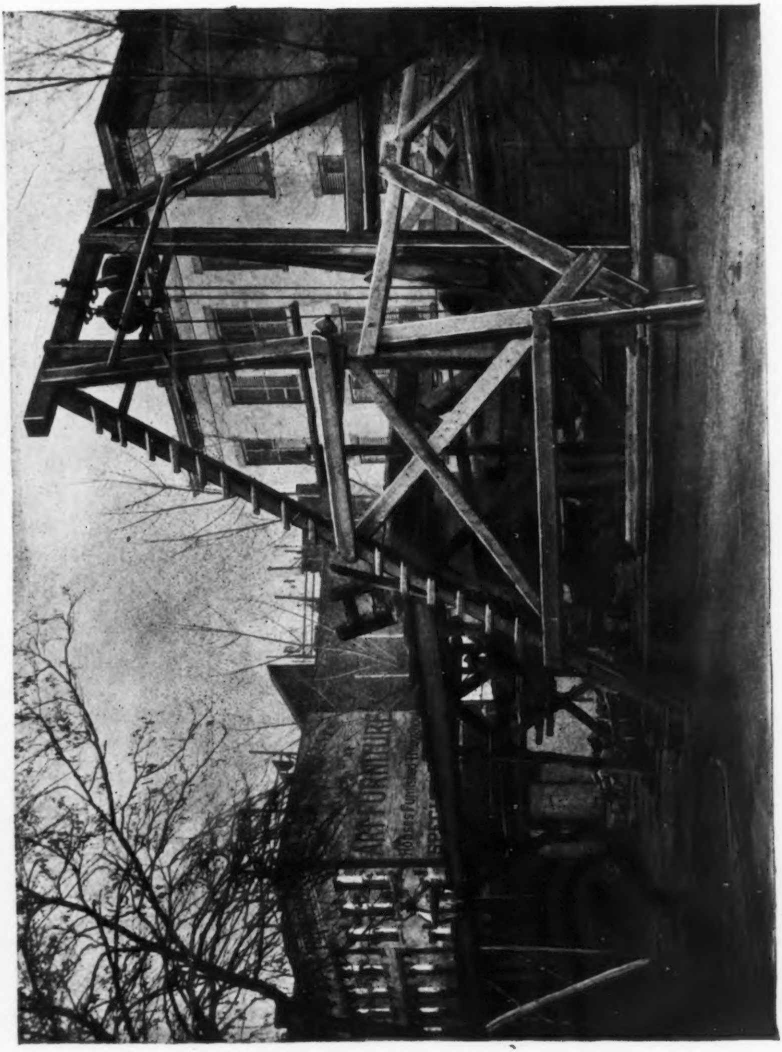

PLATE L.
TRANS. AM. SOC. CIV. ENGS.
VOL. XXVI, NO. 529.
BEAHAN ON BROOKLYN RELIEF SEWER.

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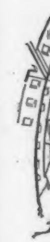

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special safeguards. In a view shown of the heading (Plate L) the roof plates are curved to the radius of the outer circle of the brickwork, and to place them there, is the desideratum in heading work; they go together in rings 1 foot long, and are carried down as far as much side pressure is felt in the material met. At each second ring a bulkhead is built down in front and braces put from the last ring to the pilot. Heading plates are kept in direction, in grade, and in correct circle, all by wedging. In short, a wooden wedge is the fine point in tunneling by the pilot system, and with sufficient practice the pilot can be guided in any direction. Even Weisbach does not fully realize the potency of a wedge. The detail of heading work has no place here; no description should induce any careful man to try to do the work without having attended school in a heading. This is a pointed reflection on engineers who visit tunnels and go away to do what they think they saw done in the way they thought they saw it done.

The view of heading work (Fig. 2) shows some features which should

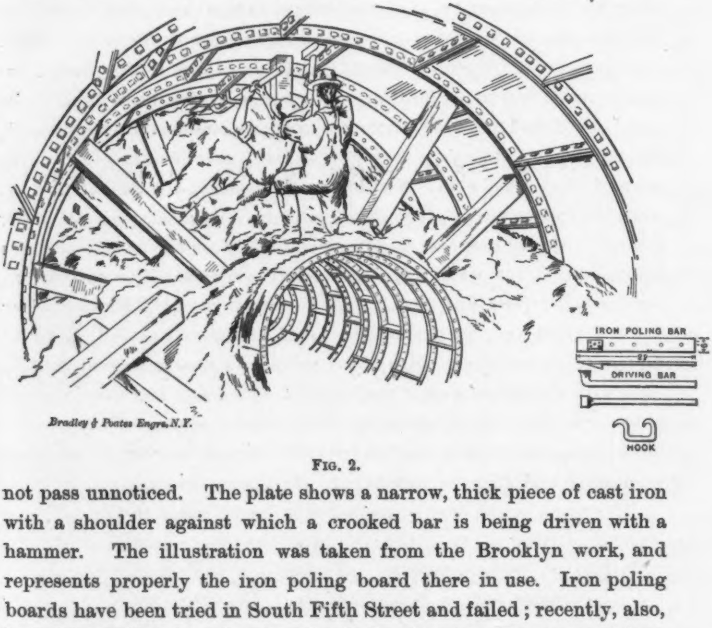


Fig. 2.

not pass unnoticed. The plate shows a narrow, thick piece of cast iron with a shoulder against which a crooked bar is being driven with a hammer. The illustration was taken from the Brooklyn work, and represents properly the iron poling board there in use. Iron poling boards have been tried in South Fifth Street and failed; recently, also, in Baltimore they have been used and abandoned. The one used here

was a success, and was designed by Superintendent Samuel Matson early in 1891, while this tunnel was under construction. It is a steel plate, one-quarter of an inch in thickness, 6 inches wide and 22 inches long, and having a wedge-shaped lug riveted to its under side, near the front end; the plate also has four holes through it at intervals of its length. The lug is for driving it with bar and hammer, and the holes are to straighten it or shift it sidewise. The poling boards are used in the heading for some 4 feet each side the center line, and for the pilot work as described, their purpose being to save loss of material in running sand, gravel, or cobble stone.

Mr. Beach has recently claimed that this iron poling board was a "needle" of his, patented in 1869. From a copy of his patent, to which he refers by number, furnished from Washington, the author finds that in connection with his shield patent, there were "sliding staves" which are staves over the end of the shield. There is no kinship in appearance between his "sliding staves" and his "needle," as illustrated. Prior to this comparison, the author thought that the poling board used was Mr. Beach's needle re-invented, a case of double discovery, which so often occurs. Engineers should insist that superintendents and foremen be given full credit for thoughtful ingenuity that bears fruit. The members of our profession are too apt to appropriate to themselves credit for much that some foreman or laborer really did when they themselves were at their wits' end. Who knows the name of the laborer who hit upon the cooper's draw-shave that was such a help in the pipe clay at St. Clair? Did any one ever hear how the shield on the Sarnia side was gotten down to the portal when presumably every means known had been tried to no purpose thus far? In the earlier work of the Hudson River Tunnel, years ago, an accident occurred and nearly a whole gang of men were buried alive. Men stood aghast; engineers were consulted, each with a different way of meeting the emergency, and the President of the company was distracted by the conflict of views. Who speedily hit upon a plan, which was successfully carried out, for rescuing the bodies and restoring the structure? He was not an engineer.

These iron poling boards are useless in heavy material without some way of driving them. The driving bar was designed with the poling board by the same man. He used a double hook to suspend it from the plates and so hold them up. The hook shown is better and replaced the first one, and was gotten up by foreman Charles

Erricson. It hangs in two bolt holes with a bar between, all in one piece. In stiff clay no iron poling boards are needed; in heavy boulders requiring much blasting they are often removed temporarily. Some skill is needed to keep them in the position desired. At the completion of the tunnel the iron poling was in great favor among both foremen and heading men. We have failed and will fail with them, mainly because we make them too large, and do not have the needed special appliances with which to handle them.

Excavation and brickwork must next be mentioned. When the heading is at least 15 feet in from the shaft, or from the toothing of the last section, a 10-foot section of brickwork is put in. The roof of the heading, lined with plates, is carried by braces on the pilot. The pilot rests for some 20 or more feet in the muck, and for the 4 feet of its length nearest the shaft on braces or blocking. The heading men start down with the excavation on the sides of the pilot and for a length of 10 feet. When they get below the bottom of the iron heading plates, they put in planks longitudinally on either side and brace these planks from the sides of the pilot. The planks are put in one below the other on the line of the outer circle of the brickwork until they are below the pilot, or where the material will stand. At the front ends of the planks a bulkhead is driven vertically, extending from the pilot to the side planking. The excavation is carried down under the pilot, and braces put underneath on foot blocks. A bulkhead is also put in underneath the pilot on a line with the front ends of the side planking, braced up, and enough braces put under the pilot to carry roof and arch. All the excavation is done carefully to the outer line of the brickwork. A profile for the invert is moved forward, set to grade line and its top cross piece leveled horizontally and set on center line; planks are put in the bottom unless the bottom be very hard, and the brickwork begun. There is no back filling or ramming. A sub-drain was planned, but a wooden box above the brickwork of the invert was used instead, and any water in the section was pumped up into this box. This was better, for the box could be taken up and cleaned out.

The best hard-burnt North River bricks were used, the ring being four courses thick. They were of a uniform quality of rough brick throughout the rings of the section. None were laid without cement, but in some very wet sections the bottom course was started dry and then

buckets of neat cement were dumped on it and spread over to fill the joints. This gave excellent results, showing no settling or percolation of water. Each course was laid to line, and the courses were tested frequently with level and straight-edge. No pains were spared to insure a strong, workmanlike job, and no time was given to effect. The cement was Rosendale, tested to resist a tensile strain of 60 pounds per square inch after 30 minutes in air and 24 hours in water. It was mixed in the proportion of one part of cement to two parts of sand. A slow-setting cement was sought, and the laboratory tests were tempered with judgment. These never showed as high tensile strength as published tests do. Much force was given to results from briquettes long made. The Department has a man who for some time has done all such work, and his deductions are comparable with themselves. Only one kind of cement was used for any ring of the brickwork.

With the same brick and the same cement every particle of space, from the neat lines of the inner surface of the sewer out to the muck, plank or plates, was built in solidly with brick laid in cement. There is not and never has been any crack in the brickwork, or any failure at any time. Where built in wet material it has settled, but it was built enough above grade at the leading end to allow for it. A brick tunnel in yielding material is sure to settle, nor is it water tight. Leaking pipes above sometimes caused a drip into the large sewer, and it is questionable whether a brick tunnel can be made water tight when built through dripping ground.

The invert of the brickwork completed, the ribs were set, and, to save room, iron ribs and not wooden centers were used, resting on planks carried by braces, one end of which rested in "put-lock" holes in the brickwork and the other against the pilot. Four ribs were used, each in two segments bolted together at the center; lagging strips were run in on these ribs, four at a time, as needed; the two bricklayers on either side, then worked up to within four courses of the center. The last lagging had a groove in its upper edge, a block lagging was placed in these two grooves next the toothing; one bricklayer started then at the toothing to put in the key, and built it out to the end of the brickwork of the section just laid. This completed a section of brickwork. After the cement had set, the ribs were struck and removed, the lagging carried back and 10 feet of the pilot were

taken down and stacked up. All was then ready for starting down the sides to excavate for the next section of brickwork whenever the heading was far enough advanced to allow it. As two headings were worked from each shaft, and heading and pilot men never left their places of work, a section of brickwork would usually be put in at one heading, and then one at the other heading.

The chapter of accidents is never long on successful work. It also removes from the chronicler all opportunity for displaying his profundity in theorizing how each accident must have occurred. Owing to a disobedience of orders, a hoisting engineer, the friction gear of whose engine had been just overhauled, let down a cage load of men when he should have tried his friction with a loaded car. Part of the way down, the men dropped too fast and some were slightly hurt. At another time a new top man fell into a car, or fell somewhere else on the cage, his cries excited the engineer, and the latter dropped cage, car and man, disabling all three. There was a foreman on the spot, or near there, who had a theory just how it must have happened, and it was a detailed theory. It was a theory, too, that he worked whichever way he assumed the man fell, and the one opportunity for advancing a theory about an accident on that whole contract was fully embraced. There was no accident in the tunnel.

Difficulties met, and how met, is in papers of this sort a topic that will bear amplification. Early in the work, a water pipe running parallel to and over the tunnel on Fourth Avenue gave way; the heading men were less trained then and had lost material needlessly. The break occurred at night, and the city employees did not at once find the proper way to shut off the pressure. Much water escaped, but no damage of moment was done.

At Franklin Avenue the surface pipe was stripped, and, during an unusually heavy rain storm one Sunday night, the surface pipe on Greene Avenue gave way where stripped, over the end of the pilot. The pressure probably lifted up the exposed pipes, as the present sewers are badly overcharged there. The trench filled, and finally the water commenced running through the pilot, carrying considerable material with it, causing a cave-in in the street. Had men been at work, the pilot could have been bulkheaded against it. Had the filled trench given enough head to the water, it might, however, have broken into the heading. This was a difficulty, on the whole, that could scarcely have

been foreseen or guarded against. The pressure upon overcharged sewers is enormous in some localities in Brooklyn. The test shaft on Hanson Place at St. Felix Street showed a small body of water not far above the tunnel roof as already stated. It was a water pocket, but was thought by the contractors to be from a leaky pipe. As the heading reached and passed under it there was a heavy drip from it, which lasted until the spot was passed. This finally ceased, probably through the water having found a way down the brick work. This water pocket could possibly have been bled, *i. e.*, a pipe driven down from the street to it and a pump used to remove the water. In Baltimore this has been done frequently. In open cut work in Boston, below tide, the foundation is kept dry owing to peculiar stratification, by a battery of connected pipes to which a pump is attached.

We have already seen that near Shaft No. 1 the entire brickwork was set high. The arch was found to settle in all the loose material. The leading iron rib was set always 1 inch high, and then the brickwork at the toothing would be found to be at true roof grade after centers were struck. In sand and gravel—in anything but silt—the invert never settled, but the arch would settle an average of 1 inch. In one wet section, with boulders and sand, a roof was known to settle 4 inches in the 10 feet. Perhaps one-half inch of this settlement should be attributed to the centers and their supports taking a bearing. Apropos to the Chicago Tunnel, under investigation at the present time, this settlement seems pertinent. In the same connection the author desires to say that we never succeeded even with Portland cement in making the roof water tight when the roof was dripping fast as the brickwork was put in. The iron plate as a cap for the rib braces was suggested by foreman Charles Lindau, and thereafter used, and it saved from one-fourth to one-half an inch of the settlement where the roof was heavy.

We now pass from evils incident to too much water, to one caused by too little. Reference is had to a very fine, dry sand that will flow like water and pour through the least crevice in a bulkhead. It was first encountered in South Fifth Street several years ago. It could not be tunneled unless made wet. Flooding it by means of a pipe driven down from the street and a hydrant attached to it, failed for some reason. Next, a hose was attached to the water-supply pipe used for cement mixing, near the heading; a short piece of water pipe

was fastened to the far end of the hose, the pipe was thrust into the sand at the roof of the heading and the water turned on. The water could not force its way in nor even soak in. Finally, a jet of water, was played upon the sand and a hole washed, into which the pipe was slowly advanced, and the sand was wetted. This worked very nicely, and the water jet was thus used throughout this portion of the work. Rarely does this sand extend all over the section in this drift material.

The care needed for water and sewer pipes overlying the tunnel depended much on the condition of these pipes. Slinging was resorted to for water pipes where danger was apprehended. The greatest annoyance was from cement sewer pipes, some of which were put down years ago by property owners and afterward accepted by the city. Having been laid under the supervision of men unfamiliar with such work, they were now found settled, broken and cracked, often leaking before the pilot reached a point under them. They were too broken to sling even on plank. Stripping them, constant tamping, Portland cement bottoms, and even plaster of Paris to caulk cracks were employed.

Under the worst-laid pipes the blasting was heaviest. Care in the heading, and constant watching and tamping of the pipes availed most. Boulders containing often a cubic yard with others to fit in the spaces, fine sand overlying and heavy rains surcharging all with water, go to make a bad surrounding in which to tunnel under a broken sewer pipe in winter. A deep hole, a small charge of black powder hard tamped and splitting the boulder into about three pieces, was found the best way to blast in the case described. The lower piece was then worked out and an upper piece let down a little so as to get in one poling board; a little more for another poling board, and so on. These rocks must be removed from the heading before pop-shotting. This is not the best way in all cases, but is best for this special one. The most useful device found for carrying water along a bad surface pipe or sewer, was a strip of heavy canvas, wide enough to come up above the water line and long enough to bridge over the broken pipe or crumbling brick. This was made tight to the surface of the pipe at the upper end by plaster of paris.

Things are sometimes seen that we had best admit we cannot explain, but unless our senses deceive us, they are facts. The author

once heard a member of the St. Louis Engineer Club, when confronted with the foot-a-day creeping of the rails across the Ead's Bridge there, throw overboard the whole puzzling problem with an "I deny the facts." It was surely facing the issue, and he was a man to do just that. The author would like to face a fact about these pilots in that way. They turn about their axes, and the line of their longitudinal flanges, which separate the plates from each other, was a spiral. Every three weeks the plates had to be shifted one hole to the right, *i. e.*, six inches. Every pilot moved in the same direction, from right to left, when looked at with the back to the shaft from which the pilot started. The direction and rate of this movement was the same for each pilot on the work. Would bad punching of the plates do this? But the pilot plates were not all made at the same place or at the same time. Each plate was put in each time just as picked up; the probabilities are that it was therefore turned around every other time it was used. Left-handed or right-handed men made no difference. All possible orders of succession of poling and bolting were tried, and no difference detected. As we worked each way from each shaft one-half the pilots rolled in one direction, the other half in an opposite direction. In South Fifth Street, it is stated, the same thing was observed, the heading plates traveling to the left when they moved at all. The movement of heading plates was very irregular—usually much less than those of the pilot. As some of you know, the shields at St. Clair and the shield in the Hudson River Tunnel revolve, and in neither case did the effort to stop the tendency or find the cause, succeed. Of course, there need be no analogy here, for shields are moved by hydraulic pressure. They do not always roll to the left, neither is the rotation always uniform.

The instrumental work of the alignment and grades was uniformly excellent. The line of levels and bench marks having been carefully established in the street, it only remained to measure vertically down the shafts with a steel tape to transfer the levels to the tunnel. Bench marks were established in the tunnel with a wye level, but grade elevations for the work were given by a combined transit and level, thus avoiding the use of two instruments in cramped quarters. A grade tack was put in the invert every 30 feet, from which the inspector tested his bottom grade, and a grade mark was placed on the center of the roof to guide him in setting up his leading rib

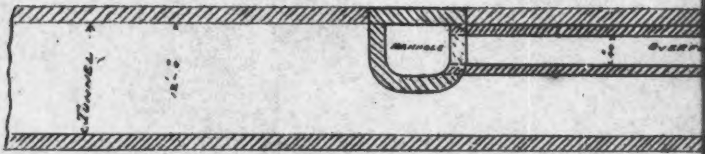
and to show the foreman how his plates must be made to run for grade. As the several headings came together the differences in levels were trifling.

The alignment was carefully established on the street and is shown in connection with the profile. The curves shown were built upon and the brickwork now stands true to them. The shafts were of different sizes. Usually, there was an available base line of 14 feet to be used in transferring the center line to the bottom of the shaft. Fine piano wire and 5-pound plumb-bobs were used, the latter steadied in a bucket of water. The transit was set up in the tunnel a little way from the shaft and shifted until its line of collimation passed through each plumb wire. A point was then established beyond the shaft in the tunnel. No point of intersection of the curves was outside the tunnel brickwork. Center points were given by tacks in the roof about 50 feet apart, nails were driven a foot ahead of each tack, and from these a long cord and a plumb bob enabled the foreman to get a center point in pilot or heading, or the inspector to center his profile for each section. The author desires to say for the benefit of his professional brethren, that centers and grades were given without any appreciable interference with the workmen. The errors in alignment found to exist as the various headings met, were too small to be now seen in the completed work. The least error in alignment was one-fourth of an inch, between Shafts No. 5 and No. 6; the greatest was 4 inches between Shafts No. 3 and No. 4. From Shaft No. 3 the line extended around two curves and for a total length of 1 400 feet to the heading. From Shaft No. 4 the line extended 780 feet to the heading, where these two lines met. These shafts were farthest apart and the long heading was on the same heading as the curves. This error of 4 inches under these conditions is not large, but first-class transit work; it certainly needed to be no better for the occasion. Mr. Wm. T. Brourton, the engineer in charge of the field work, also had charge of that work on the Knickerbocker Avenue Extension Sewer in South Fifth Street, Brooklyn. It is his judgment that for shafts giving a 14-foot base line in the tunnel and with those shafts 1 600 feet apart the maximum error in alignment of 2 inches and the maximum error in levels of one-fourth of an inch are reasonable errors.

On the profile is shown the progress in months from each heading after the work was well under way. The average progress in a heading for each 24 hours was 4.4 feet.

It only remains to speak of the special constructions employed. The sewer under consideration is a relief sewer, and therefore has no street or house connections. At Marcy, Nostrand and Bedford Avenues manholes were put in and a connection made with the surface sewers. One of these manholes and connections, the one at Bedford Avenue, is shown in detail (Plate LI); it is typical in idea with the others, although each is built on a special plan designed to apply to the case. The end sought is to avoid disturbing the house drainage of the small sewer, but to take from the small sewer all water in excess of that from house drainage and to do this with the least impeding of the flow. The connection is brought into the small sewer at as easy an angle as possible. A single slab of stone placed in the line of the down stream side of the inlet, completely cuts off all flow above its lower edge. The excess water is led to the manhole and drops vertically to the invert of the tunnel masonry. This invert has previously been paved with granite blocks such as are used on streets; the granite replaces the inner rings of brick and is laid in Portland cement to the same inner lines. It extends for 30 feet in length and up to the springing lines, and manholes were put in at every shaft except No. 7, and at Marcy, Nostrand and Grand Avenues as well. Where the diameter of the tunnel was changed from 12 to 14 feet, it was done in one 16-foot section of brickwork. Raising the ribs on the small section and lowering them on the large section started the brickwork in the changed direction and gave a gradual change of section when finished. The curve used in turning into Greene Avenue was a long curve, and put in with straight 10-foot sections of brickwork, each section of which was a chord to the circle. This was thought preferable in every way to a short circle and curved brickwork. It impedes flow less, is easier to lay brick to, and a pilot can very easily be turned around it by wedging only. It is better than a short curve, an angle, or a turn in the shaft.

The manholes on Section No. 1 are smaller and more numerous. The I-beams rest on a granite coping on the side walls of the flat roofed portion; between the beams are flat brick arches carrying the street, and all possible head room was economized. The trap basin is worthy of close study. The illustrations are so complete that it is necessary to touch only upon a few points not shown, but evident on reflection. The size of this basin, 60 feet by 84 feet and 16 feet high, is realized only

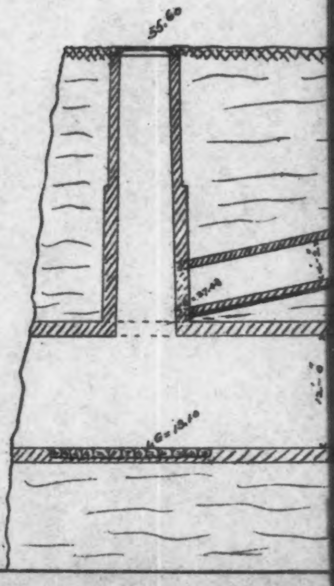


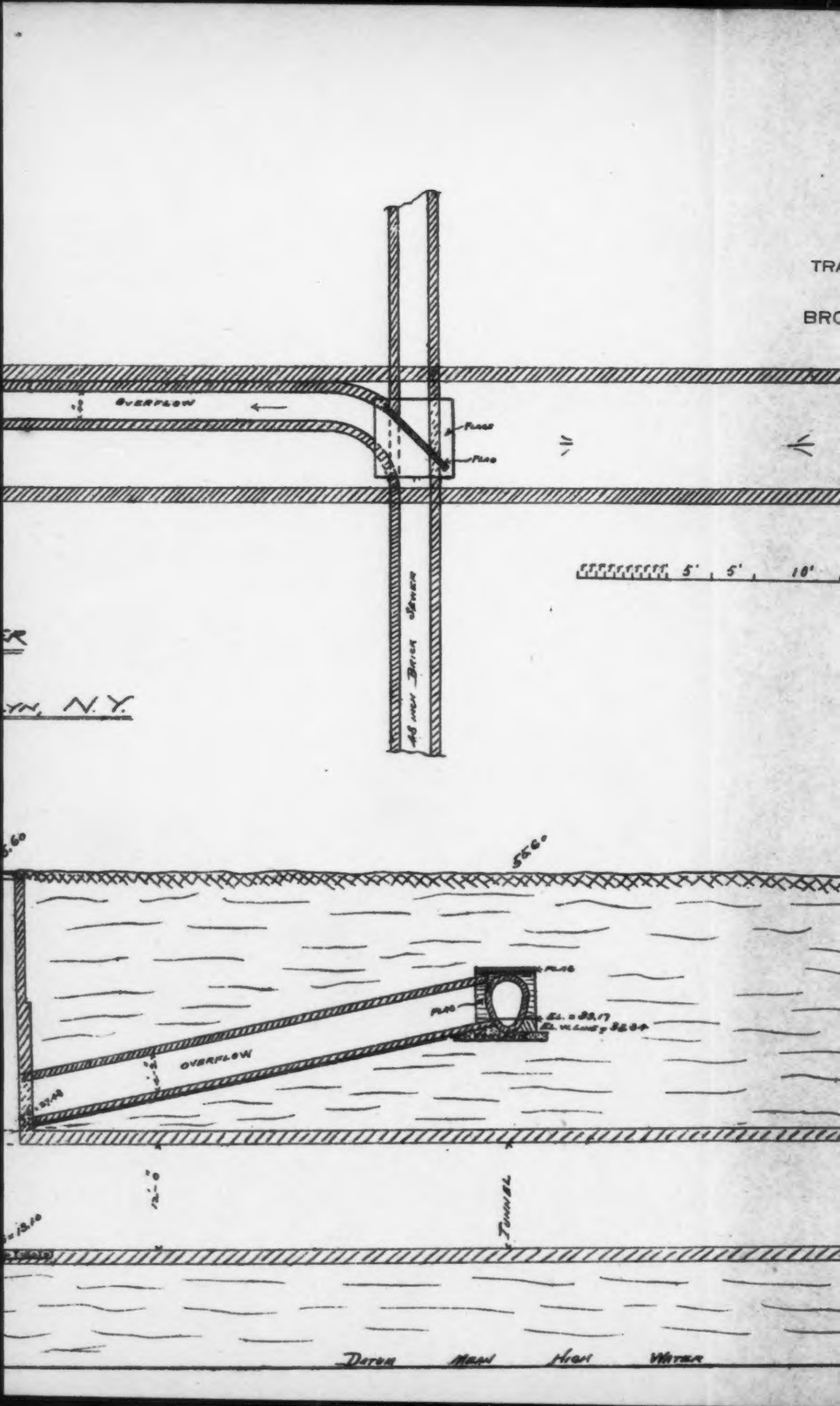
BEDFORD AVE OVERFLOW

MAIN RELIEF SEWER

BROOKLYN, N.Y.

CROSS SECTION OF OVERFLOW

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OVERFLOW
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PLUG
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OVERFLOW
PLUG
PLUG
TUNNEL
12'-0"
DATUM MEAN HIGH WATER

PLATE LI.
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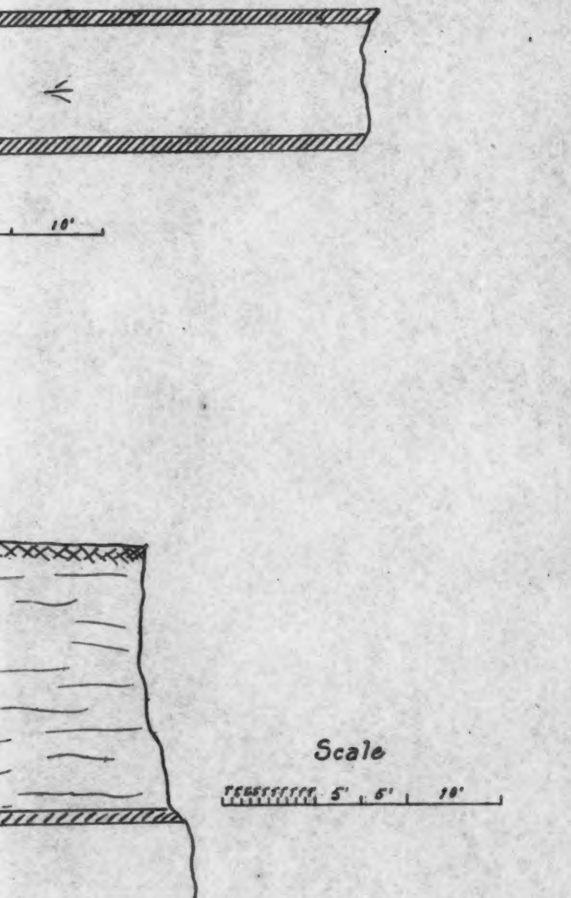
BEAHAN ON
BROOKLYN RELIEF SEWER.



when one is in it. Its duty is to receive the entire discharge; pass it through a battery of cast-iron pipes lying in a horizontal row; conduct it over a bridge wall, and then through a second and similar battery of pipes into tide water at the head of Gowanus Canal. To insure that the sewer outflow be trapped at any possible stage of the tide water is the object of the bridge described and this is apparently an unique method. The top of this bridge is 1 foot above mean low water, while the bottom of the sewer invert is at mean high water.

The Main Relief Sewer of the City of Brooklyn is an accomplished fact, well planned, successfully accomplished in a short time without a single accident or misunderstanding. In the securing of data for the preparation of this paper, the author is greatly indebted to Mr. John P. Adams, Commissioner of City Works, for the information kindly placed at his disposal through Mr. Robert Van Buren, Chief Engineer. His sincere thanks are also due to Mr. L. Russell Clapp, Assistant Engineer in charge, for kind assistance and time cheerfully granted.

DISCUSSION.

ALFRED F. SEARS, M. Am. Soc. C. E.—This paper is a description of the plans of the Main Relief Sewer of Brooklyn, with a statement of some of the expedients resorted to for overcoming difficulties in its construction. As an agreeably written, historical sketch it is pleasant reading. It is much to be regretted that the author did not enter more fully into the details of the work, some of which I venture to suggest. This would have added greatly to its value to all who are engaged in this class of Hydraulic operations.

First.—We are told "that the maximum rainfall per hour is 4 inches, and that, of this, 1 inch per hour reaches the sewer as a maximum." But the statement is also made that this 1 inch per hour "is assumed." After this, we are given an example of the application of Kutter's formula with Flynn's improvement. Now, my comment on this point is, that the application of the formula goes without saying; having a certain amount of water to accommodate, we know exactly where to go in our books to find the size of the conduit. But it would be extremely useful to have the course of reasoning by which an engineer determines that 1 inch out of a shower of 4 inches will reach certain points along the street gutters, and not 2 inches nor simply a half-inch. If Mr. Beahan will give us this argument he will do a great

deal for the advocates of what is known as the "Combined System of Sewerage," provided, always, he can show anything more than the guess-work, which has so often brought to grief the construction of sewerage works otherwise sound.

Second.—We read that "the cost for timber would be great in Brooklyn." Now, this is a very wide country, and Brooklyn is on the extreme eastern edge of it. The papers of this society must be made as useful to me on the Pacific coast where I can have the best yellow fir delivered on my work at $9.00 per M. B. M., and iron costs me, when cheapest, $50 to $60 per ton, as to you who live right here and know, perhaps, what Mr. Beahan is talking about, when he says "cost is great," which I certainly do not; if he will give us a detailed estimate on carefully drawn plans, of the cost of constructing these different designs, then we can apply the figures according to the geography of the case; without such detail the value of the statement is very limited.

Third.—The sole value to this Society, of papers telling us the story of construction, lies in the minuteness and accuracy of their details. If Mr. Beahan will tell us the number of days' labor, the class and cost of the labor it took, to do certain excavations and back fillings; also the cost of skilled labor and of the materials employed, this paper will be of much greater value. I hope he will see his way clear to do this, for which he is so competent, and so place us under greater obligations to him.

A. Fteley, M. Am. Soc. C. E.—I have read the paper that you have heard, and I might add a few remarks. One thing that I see by this paper, with a great deal of pleasure, is that the cost of the work as it stands to-day has been within the limits of the original estimate. This result upon a work that has presented so much difficulty and difficulties of such various kinds, it seems to me is a result that we must all consider as very flattering to the engineer who planned the work.

I notice in the paper a few remarks made about the reliability of soundings. I believe that in the work under consideration there were some errors shown and there were some difficulties encountered thereby, but I may be permitted to say, that, having had under my observation a great many soundings, there are means of making soundings by which the ground can be explored with a great deal of accuracy, so as to give to the engineer a good idea about the work that is to be done.

I notice also that in the computations of flow, the Kutter coefficient n has been estimated as being .015. I believe that figure is altogether too high; from data I have of the work under consideration I do not doubt that the coefficient would certainly be as low as .014, and considering the important bearing of the coefficient I do not doubt that the flow ought to show more than represented in that calculation.

I notice also that the maximum error in the tunnel in alignment has

been considered as being a maximum of 2 inches in a shaft presenting a base of 14 feet for a heading of 1 600 feet. I do not myself attach a great deal of importance to the absolute accuracy of alignments in work of this kind; sometimes a great deal of time is spent in getting absolute accuracy. I should say we have lately in tunnel building attained some results very much more exact. We have seen many results in which the error was a very small fraction of the maximum mentioned for a heading as long as 7 500 feet.

It may be permitted also, as I see there is not present any engineer who had anything to do with this work, to say, as it was my good fortune to be consulted some years ago when this scheme was planned, that the study of the present sewer required heroic treatment. The engineer who recommended this sewer had also recommended another portion which has not been accepted. All the portion of Brooklyn which adjoins the Wallabout is so very level that when a large amount of flow reaches that region, the streets are very much flooded, and it is very difficult to prevent flooding. It was suggested that the whole district might be raised a number of feet. It was not then very thickly built upon, and the expenditure would have been within some reasonable amount. As an engineer, I am sorry that the details of the matter were not more fully considered than they were. I don't doubt, however, that a portion of the trouble there would be relieved by the fact that a portion of the overflow water of the district will be taken care of by this Greene Avenue sewer.

On the whole, this work has been very satisfactorily conducted throughout. We have heard little of it because it was so well conducted that there was not any accident. It was a great work; it was carried on under the main street and under heavy buildings, and no trouble was experienced at all, and it does a great deal of credit to the people who have planned the work.

Mr. Beahan.—Do you consider that .014 would be about the right coefficient for North River brick in joints not struck ?

Mr. Fteley.—I must say that I have not seen the last part of the work. I saw it at the beginning, and, judging from other structures of the same kind where the joints were not struck, I believe that .015 is the very extreme coefficient that ought to adopted, and it should be very rough indeed to obtain that figure. On a very large work in which I am now measuring the water, I find, within the last two or three months, that from .0146 to .0142 is about the limit.

A. McC. Parker, M. Am. Soc. C. E.—I once had to sink a shaft about 120 feet along the footwall, through a pile of loose material made up of earth, dirt and broken rock, some of which was in very large masses, in a pit at the Tilly Foster Iron Mine. A pit 8 x 10 feet at the bottom was dug in the top of the pile as deep as it could be safely carried down. In the bottom of this pit a shaft set, made of flatted

round oak timber, 10 inches in diameter at the small end, was laid at an angle of about 80 degrees with the dip of the shaft. Corresponding sets placed 4 feet apart were placed above this, up to the level of the top of the pile of loose material and then 2-inch oak poling boards, not over 9 inches wide, were driven all around and the pit filled in and tamped thoroughly. The lower set of poling boards was then driven, one by one, until about 6 feet had been excavated, when another timber set was placed and a new set of poling boards started. When the poling boards were driven they bore against the dirt on the outside of the cap of a lower set (tending to crowd the cap toward the wall), and on the inside of the cap of an upper set (tending to pull it out), but this pull was resisted by the pressure against the boards already driven; consequently, the harder the boards were driven, the stronger the shaft became. The sets were partly supported by the friction of the poling boards, and partly by setting them, not normal to the dip of the shaft, but at an angle considerably above the normal, so that, as they tended to settle down at the cap end (the foot being supported by the foot wall), they became longer in a direction normal to the dip and consequently exerted a thrust against the overlying dirt; hence, the greater tendency to settle, the stronger the shaft-timbering became.

O. F. Nichols, M. Am. Soc. C. E.—This is, so far as I know, one of the first occasions in which this "pilot system" of tunneling has been presented before an engineering society. I regret that Mr. Beahan has not gone into the question of cost. It would have been extremely interesting if we could, at least, have had the average number of men employed at each heading. I am still in hopes that the engineers who designed and inspected this work may, in their reports or otherwise, give us many valuable details which are wanting in this paper.

The system seems to me to have very marked advantages in certain places, and Brooklyn seems to be one of the most suitable localities for its application. The same system was used by Mr. Anderson, I think, on the South Fifth Street sewer, which was one of the earlier sewer tunnels in Brooklyn. There had been great settlement on that work, and many difficulties in open work and tunnel. This system was adopted, property was saved from destruction, and the contractors avoided serious financial loss.

I have observed the work on the Greene Avenue sewer with great interest and mainly as one who would be seriously affected if it should fail during construction. The work has been pushed rapidly and with great care and skill. This Long Island material is, as we all know, a compact drift of fine sand, gravel and boulders. Where the material is sand, it is often clean, sharp and compact, and, under these conditions, this method of tunneling has been very satisfactory when the ground could be kept dry. Whenever boulders have been found, the compacting of these together in mass has arched the material over the tunnel

in a way to avoid great settlement and loss of material. The settlement of the street surface has generally been very slight, no buildings have settled, no structures have been jeopardized. At Flatbush Avenue an elevated railroad foundation within the settlement area settled less than one-half inch, the moving load having been taken off during construction, at this point the general surface settlement had been considerable, due to the necessity of pumping from below the invert. At Grand Avenue, of six foundations of the same kind, nearly over the sewer, one has settled not more than an inch, and the others have not settled at all. The material here is compacted boulders, and pumping was not necessary. Altogether, I doubt if corresponding results over such a length of tunnel could have been secured by any other method.

A disadvantage of the system would seem to be that so few men can be worked in the headings, the pilot and braces fill up so much of the space for a considerable length of tunnel. A great advantage on the other hand, particularly for cases of this kind in crowded streets, is that so little constructive material had to be handled through the shafts, no heavy or long timbers being required. The iron segments are taken in and remain there in progressive use with a minimum amount of timber, until the headings meet. Messrs. Anderson & Barr have had long and varied experience in the use of this pilot system and have reduced the delay, danger and expense to a minimum. I am, on this account, the more desirous that some one should give us details of the cost of this particular work, that we may compare it with other systems with which we are better acquainted.

Mr. Beahan makes sweeping criticisms of the shield system. It must be remembered that shields have generally been introduced where the loss of material and lives have been considerable before they were introduced. Such was the case on the old Thames Tunnel, the Hudson River, the Mersey and the St. Clair Tunnels. The engineers were not justified from previous experience, in the St. Clair Tunnel, in using any other method, and the repeated failures to get beyond the bulkhead line on the New York side of the Hudson River Tunnel, certainly justified the proposed resort to a shield as the safest method of doing this work.

The use of a shield in compact rock, as proposed for the deep rapid-transit tunnel in New York City, is simply absurd. The various attempts to tie us down to some particular patented shield are ridiculous. Shields like everything else are subject to betterment based on continued use in various materials. A perfect shield is therefore more likely to be the result of future development than of past patent right. Mr. Beahan becomes unnecessarily sarcastic in his preference for the practical school, and in demanding recognition for the services rendered by skilled workmen. No sensible engineer will theorize over the execution of a work of this kind. When he plans and projects, he neces-

sarily uses theories and formulas; when he meets material in the physical sense, he meets it in a practical way with every agency at his hand, to overcome its resistances, and from Brunel to Fteley no ingenious device for accomplishing rapid, economical and, hence, successful work, fails of prompt recognition; and no laborer, however humble, who can add a valuable suggestion to the sum of engineering experience, fails to find applause from the conscientious engineer. "Let us be honest," says Mr. Beahan, and in saying this he implies an unwarranted arrogance and iniquity to a profession which is, of all professions, the most honest and the quickest to detect and expose fraud. Two foreman find recognition in this paper. Unless the work is very different from other work, there are others whose quiet efforts may have deserved it more. Published recognition is what the best workers, as laborers or engineers, seek last; it is the lesson of all biography, that modesty is the crowning attribute of the greatest. Only the time-server, the self-seeker, the vain-glorious and the schemer fail of that which is the best and often the only recognition of the faithful worker—the consciousness of duty well done under every trial.

Charles B. Brush, Vice-President Am. Soc. C. E.—The pilot system has been referred to a number of times this evening and it has also been discussed at considerable length on other occasions. It may be interesting to review the history of this system.

In the commencement of the construction of the Hudson River Tunnel a shaft was sunk 30 feet in diameter and 60 feet deep. The idea was that opposite sides of the shaft could be removed and the tunnel started directly in the silt. Large rings were built in the sides of the shaft as it was sunk, and provision was made so that the brick work could be taken out from inside of these rings and the tunnel started from these points. The attempt resulted in failure. An opening was made through the shaft, the excavation was commenced in the silt and for one or two days it worked very well. The opening was excavated for a width in the top of the heading of perhaps 12 feet and the heading was kept in place partly by timber bracing. On the third day it was noticed that this was failing and on the fourth day it failed entirely. An air lock had been placed through the brick work in the side of the shaft, and air under pressure was forced into the opening made into the silt. It was hoped that, without any further protection, the air pressure would be sufficient to hold the silt in place. The timbering to which I referred was very slight.

A number of methods were then considered. A roof was built over that portion of the tunnel where the excavation had been made, and this roof was covered with timber and some canvas, and again they attempted to make the excavation on the same principle, that is, to sustain the roof and sides simply by forcing air into the excavation,

but it was unsuccessful. This occurred and was described in a paper presented to this society, and read May 25th, 1880.* The failure took place, as recorded in that paper, on January 5th, 1880.

The next thing that was done is described on page 267, viz.: "Plates for an iron tube 8 feet long and 6 feet 4 inches in diameter were ordered, the plates to be ½ inch thick, 2 feet 6 inches wide and 4 feet long, with 3-inch angle iron flanges riveted to the four sides of the plates." They were made just large enough to surround the airlock as it projected through the side walls of the shaft. These plates were put in position exactly as described, and thereafter no difficulty was found in working the material.

The question then arose as to how much area of heading could be satisfactorily worked in this way. For the purpose of determining that point, a series of concentric rings were then constructed and placed in position, gradually enlarging in diameter until the full size of the tunnel was reached. It was found that these rings assisted in keeping the material in place, but that the size of the original tube was the most convenient for use in making the heading. This original iron tube was the beginning of the whole pilot system, and it was proposed and designed by me. It was used during the balance of the construction of the tunnel while Mr. Anderson remained as Superintendent. What I have stated are simply historic facts.

Mr. Beahan.—I am perfectly aware that I am not giving any history of the pilot, nor am I here to answer the gentleman as to who invented the pilot or as to whether any man ever invented it all by himself. I do not know. I have not called it the Anderson system at all, as you will find; nor do I mean to disclaim anything the gentleman said. Mr. Anderson is not present; Mr. Brush has the floor and has the advantage of me. In reading the paper that Mr. Brush refers to, I never noticed that that was a pilot. It is a fair section of that tunnel, the concentric rings run from a small to a large one, and, as it started from that shaft, I don't see that it was a pilot. The idea of the pilot is that of a small experimental tunnel in advance of the main tunnel. One of the reasons, I suppose the first reason for using it, was to find out the nature of the material in advance; if there is bad material, the pilot will run into it and it can be prepared for. The pilot can be bulkheaded easily, when a tunnel 20 feet in diameter could not.

As to this discussion to which Mr. Brush has referred I confess I am not equal to it in any way.

Mr. Brush.—A tube about 6 feet in diameter proved to be the most convenient size for working with the advance tunnel, and with such an advance tunnel it was found that the work could proceed much more rapidly and the proper section of the tunnel could be more accurately obtained. It was also valuable for the purpose of exploring.

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* *Transactions* Am. Soc. C. E., Vol. IX, p. 259.

T. H. McCann, M. Am. Soc. C. E.—Mr. Beahan states that the "pilot system" of tunneling was first introduced by Mr. J. F. Anderson, Superintendent of the Hudson River Tunnel, in 1880. At the beginning of the work of this tunnel, in 1880, I was in daily attendance with C. B. Brush, M. Am. Soc. C. E., the Chief Engineer, and generally present during the discussions of methods to overcome the various difficulties that presented themselves from time to time. I have always had the conviction that the suggestion of the "pilot" was first made by Mr. Brush.

It is true, as Mr. Beahan states, that Superintendent Anderson introduced the practical working of the "pilot system," and there is no doubt that his skill and courageous energy made the experiment a success from the start. Now, whether the germ of the idea originated in the brain of Mr. Brush or that of Mr. Anderson will, I suppose, to engineers a thousand years hence make little difference, but it is only just that this testimony be entered here in order to render honor to whom honor is due. As all of us very well know, during a discussion in which several original minds are engaged on some difficult and intricate problem, new and novel ideas will be suggested; but if any one of the participants in the discussion were to be asked some years afterwards to whom a certain idea in the solution should be accredited, it is ten chances to one that he would not be able to remember.

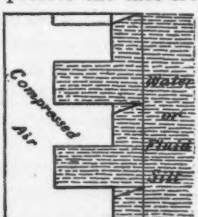
The principal use of the "pilot" in the Hudson River Tunnel heading was for doing away with long stud bracing, and for assisting the workmen in keeping the iron plates closer to the normal cross-section. The second purpose was to act as an explorer. These are virtually the same purposes for which it was employed in the Brooklyn sewer as described by Mr. Beahan. It was at the very first excavations made for the Hudson River Tunnel that the introduction of the "pilot system" may be considered as having been made. But it was not until after the work was well under way that the system as described by Mr. Beahan was fully developed.

A brief description of the tunnel work will probably not be out of place here, although a full account may be found in the paper of Messrs. Spielmann & Brush, read at the Twelfth Annual Convention of the Society, May 25th, 1880. A brick shaft, 30 feet in diameter, was sunk to a point 60 feet below high water on the Jersey shore of the Hudson River. This was refilled for a depth of 30 feet, and at that elevation a horizontal air lock 6 feet in diameter was placed; the intention being to use (and, so far as I know, for the first time) compressed air horizontally. After the air lock had been placed in position, iron plates 2 feet 6 inches wide and 4 feet long, were forced out into the silt at the heading, so as to form a tube 6 feet in diameter, which was carried on for a distance of 12 feet. This 6-foot explorer proved of valuable service, for the silt being overlaid with ashes and loose soil

(with which the land forming the bulkhead was made) permitted the air to escape and a cave in was the result. An excavation to the depth of about 5 feet was then made on the surface of the ground and a sheet of canvas heavily weighted was placed over the heading. This was a success, and we were thus enabled to keep the air pretty well confined in the tube.

As each successive ring was constructed with the iron plates, the diameter was gradually increased—always keeping the top level—until a diameter of 18 feet was attained, and in this way a cone was gradually formed which at the end of 40 feet brought us to the grade of the bottom of the tunnel, about 60 feet below high water. The excavation was then continued with this diameter, keeping the tunnel to its proper grade, the brick lining 16 inches thick following up as close as practical to the heading. In this manner the tunnel was carried on for about 200 feet, but as it had been found almost impossible to keep the iron rings to their true cross-sectional form, even with the combination of compressed air and timber bracing, it was then that the "pilot" idea, as described by Mr. Beahan, suggested itself. As soon as the "pilot" was introduced, better workmanship and a truer cross-section was obtained, and was continued successfully in use during my stay on the work.

W. R. Hutton, M. Am. Soc. C. E.—The shield when used for tunneling has a double duty to perform. It must protect the face from the inflow of material, and it must support the perimeter while the lining is being built. Brunel's, the first shield, accomplished both these purposes. That of Barlow, in 1863, was needed for the second purpose only, as the workmen stood in front of the shield and excavated a way for its advance. The Beach shield was originally designed for sand, dividing up the natural slope of that in the face, into several lower and therefore shorter slopes by horizontal shelves. Evidently, therefore, the Beach shield was not used in the South 5th Street Tunnel (in Brooklyn) by Anderson & Barr.



Section of Baker's shield.

The St. Clair, and the Greathead (City and South London) shields have some further improvements, and a shield designed by Sir Benjamin Baker contains a "compressed-air-seal," as it may be called, between the double diaphragms. Although the material through which the St. Clair Tunnel is made—a soft blue clay—is very different from the silt in which the Hudson Tunnel lies, yet previous experience in attempts to tunnel the Detroit River (see *Transactions* Am. Soc. C. E., Vol. II, 233), fully justifies Sir Henry Tyler and Mr. Hobson in the use of a shield. They deserve great praise for the skillful design and management of it.

Although compressed air has been used with the shield in the more recent works, the latter is not by any means a "pneumatic appliance." Except at special points, the air pressure was used in the St. Clair Tunnel, not to support the face, but to balance the pressure of the gas in the gravel with which the blue clay was underlaid, and which caused the failure of the previous attempts to tunnel under this river. The original Beach shield was not aided by air pressure. Presumably, that used in South Fifth Street was not, and air was not used normally in the City and South London Tunnel. In the Hudson Tunnel it is probable that an excess of material would flow in through the openings in the shield if air were not used, but no attempt was made to dispense with it, because the men—the older ones, trained under the Haskin system—thought the safety of the work and of themselves depended on a good pressure of air. If, as the author states, the shield is not indispensable in tunneling through the Hudson River silt, it would be interesting to know what method he would substitute. A return to the "pilot system" would be not only unwise, but criminal.

WILLARD BEAHAN, M. Am. Soc. C. E.—In reply, I will first answer the remarks made by Mr. Sears. As to the items of cost, I have given the progress each month from each heading, but have not given the number of days' work it would take to do it. Contractors do not usually give fuller information.

As for the assumption that one inch an hour reaches the sewer in a 4-inch rainfall, I cannot give the data to-night on which it was based; it was, of course, after a series of experiments. That was given me by Mr. Van Buren as what they had found through a long term of years, something like thirty-five, that 4 inches was the maximum rainfall. I should suppose Mr. Sears assumes that one-half of that rainfall goes off every hour. This sewer does not take all of the storm water of that portion of Brooklyn that it relieves. If you will look at the plan of the manhole you will find that considerable of the outflow of the older portion is still overflow of storm water. As to the cost of timber, it is variable according to the time and place where it is purchased.

The question has been asked whether there was any difficulty in keeping the poling boards close together. There was none. The difficulty with an iron poling board is that it is inclined to drop down on the side; in the roof they are quite as apt to drop down as to drop away from each other. The reason why I think they succeeded in this case, and yet have failed when used elsewhere, is that we have a smaller poling board, and it can be moved back to place. Boards 4 or 5 feet long have been used, but cannot be kept in place; they get out of position and drop down. At Baltimore they tried such poling boards and pronounced them failures, but the small ones used in Brooklyn were certainly a success.

Mr. Hutton, in his discussion, says, "to return to the pilot system

in the Hudson River Tunnel would be criminal." Were any men killed in the Hudson River Tunnel when the pilot was used? Mr. Moier has stated to me that had they any men on the work now who were familiar with the pilot system they could get along all right without a shield. Still, I think it is proper to use a shield for the Hudson River Tunnel. The pilot was invented there for that form of material; still, I think if I was tunneling out under the Hudson River, with the possibility of coming out to clear water, I certainly should want a shield. Sir Benjamin Baker claimed for the water space between his two shields that it was perfectly practicable to tunnel through clear water with his system, but Mr. Moier assured me that when Sir Benjamin attempted to do so *he* would rather be on the top of the river in a boat.

The question is also asked whether much material slipped into the tunnel from above the top of the arch. There was some such slipping, as could be seen by the depression of the streets. Through the heavy cut between Shafts 4 and 5, we lost none that we know of; the amount depends on the material passed through. If the material will stand a half a minute, there will be but little material lost, but if there are boulders above the arch (and I have seen them so thick that nothing else could be seen), then the water would come in with the sand and keep carrying it down all the time. We could not protect ourselves when we had boulders with water, and naturally we would lose much material. This, it may be noticed, is not a machine method, but a method of manual labor, and the kind of men and the kind of foremen employed make a great deal of difference in the result.

No water pipes were broken from the settlement of the earth, but there were some sewer pipes broken; these were laid badly and dipped up and down and settled in various ways, and they were leaking before we got to them.

As to the nationality of the laborers which has been enquired about, we had more Swedes than anything else among the heading men, because the Scandinavians who come here are mostly sailors and of a more mechanical turn of mind than other laborers, and can be broken in better. The next nationality was Irish, some of them were the best sort of men, but they have the common failing of all Irishmen after pay day.

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(Vol. XXVI.—May, 1892.)

DISCUSSION ON PAPER No. 511 ON THE BRAZOS RIVER HARBOR IMPROVEMENT.

By WILLIAM P. CRAIGHILL, M. Am. Soc. C. E., and
E. L. CORTHELL, M. Am. Soc. C. E.

WILLIAM P. CRAIGHILL, M. Am. Soc. C. E.—In the interesting discussion of Mr. Wisner's paper on the Brazos River Harbor Improvement, I find Mr. LeBaron has fallen into an error, on page 554, in saying that certain mattresses there described were designed by General Gillmore. They had their origin on the Cape Fear River in the following way: We were trying to do what my predecessors had been working at occasionally for nearly a century, viz., to close the New Inlet, a mouth of the Cape Fear which had been open about a hundred years, to the great detriment of the original and proper mouth at the Baldhead. In that century it had become nearly as good a channel as the old one. It was a mile wide and quite deep, and there were the tides and waves of the ocean to contend with, as well as the currents of the river.

It was decided to effect the closure by dumping stone and thus forming a dam. As usual in Government operations of this kind, it was necessary to work with limited means and as economically as possible. It was thought necessary to lay mattresses of some kind for the dumped stone to fall upon. There were no facilities for speedily constructing the regular mattress which had been so extensively used on the Mississippi River and elsewhere in this and other countries. North Carolina, as is known, abounds in pine, and of this wood there was a heavy growth on the banks of the creeks emptying into the Cape Fear near the New Inlet. The idea occurred to me to make rafts of these pine logs, by cutting them on the banks of the secondary streams, and rolling them into the water. Upon these rafts brush from the tops and branches of the trees was placed so that each raft carried a full load and had its top just level with the water. They were towed into position and sunk by dumping stone on them. The idea was adopted by one of the bidders and his bid was founded upon it.

Later, he became a contractor on the jetties at Charleston and the same kind of mattress was used there under the direction of General Gillmore. It is cheap and answers in some respects quite well, but it has, however, defects. It is rather too rigid except for very soft material. Sometimes, unless the mattress be entirely sunk in the material at the bottom, there is a hurtful escape of water through the raft between the bottom logs, producing scour where not wanted. Sometimes, in a heavy sea, such as frequently prevails on the bar at Charleston, a raft is not sunk flat or becomes partly broken, and detached logs rise to or near the surface like snags or sawyers and become dangerous to passing vessels.

This improvement was quite a successful one. An interesting account of it may be found in the Annual Report of the Chief of Engineers of the Army for 1886, pages 1004–11. When the new inlet was closed, the old mouth, six miles distant, increased in depth from 9 to 15 feet at low water.

A curious piece of the history of this form of mattress is, that the contractor referred to had the brass to take out a patent on it, and demanded damages for the use of his patent. My impression is he never received anything from General Gillmore, and I am quite sure he never did from me.

This economical operation in the line of producing a cheap mat-

tress, reminds me of another practiced years before on the Susquehanna River, near Havre-de-Grace, where are now the fine bridges of the Pennsylvania and Baltimore and Ohio Railroads. In order to maintain the navigation of the main channel to Havre-de-Grace, it was necessary to close a secondary channel. There was but little money available. It occurred to me to utilize the products of that country also, as was later done on the Cape Fear. An old canal enters the Susquehanna a little distance above Havre-de-Grace. In that vicinity were a number of old canal boats of little value, that could be purchased for little money. A number of them were bought and towed to the quarries of Port Deposit, which is quite near. They were cheaply loaded with as much stone (quarry groat) as they would carry. They were then towed into position and, by the addition of a little more stone carried on auxiliary scows, were sunk in one or more tiers. The operation was very cheap and the result very good.

In this same vicinity there was a question of improving the wide stretch of the Susquehanna below Havre-de-Grace, by regulating works, although the fishermen objected very much to anything of that kind that would interfere with nets. A movable deflector or training wall was built with the view of determining the best position for a permanent one when more money should be available. The experiment gave valuable information, and the materials of the movable training wall were later used in a fixed one.

We are now wrestling with the problem of preventing the ice gorges which occasionally form at and near Havre-de-Grace on this same river —Susquehanna—of which very disagreeable effects are felt at Port Deposit, several miles above.

E. L. Corthell, M. Am. Soc. C. E.—Under date of June 7th, 1892, Mr. Corthell writes: "I have recently examined the Brazos River jetties, and although incomplete and the last 2 000 feet under water from 3 to 6 feet, there is now a channel 20 to 25 feet deep entirely to the end of the jetties, with only one sounding of 18½ feet, with 19 feet each side and 25 feet within 400 feet of the ends of the jetties.

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NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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BRIDGING CAÑONS LENGTHWISE.

By HOWARD V. HINCKLEY, M. Am. Soc. C. E.

It is not my purpose to present a treatise on how to bridge cañons lengthwise, but simply to show the peculiar features of bridges that have been used in two instances in the solution of this problem.

Case 1 is in the Apache Cañon of the Rio Galisteo, on the main line of the New Mexico and Southern Pacific Railroad (Santa Fé route), just east of Lamy, in Santa Fé County, New Mexico. This point is at mile 832 west of Atchison and 1 307 west of Chicago.

Fig. 1 is a map of alignment and river crossings.

Fig. 2 is a profile of river crossings.

Fig. 3 is a plan of the bridge.

Fig. 4 is a cross-section of the cañon showing center support of bridge.

The ends of the bridge rest on abutments on opposite sides of the cañon. The center line of the track is on a ten-degree curve, and is 14½ inches off the center line of the plate girder bridge at the center and at both ends of the span.

Case 2 is in the Royal Gorge (of the Grand Cañon) of the Arkansas

River, 2 miles west of Cañon City, in Fremont County, Colo., at mile 1 135 west of Chicago. This bridge is popularly known as the hanging bridge.

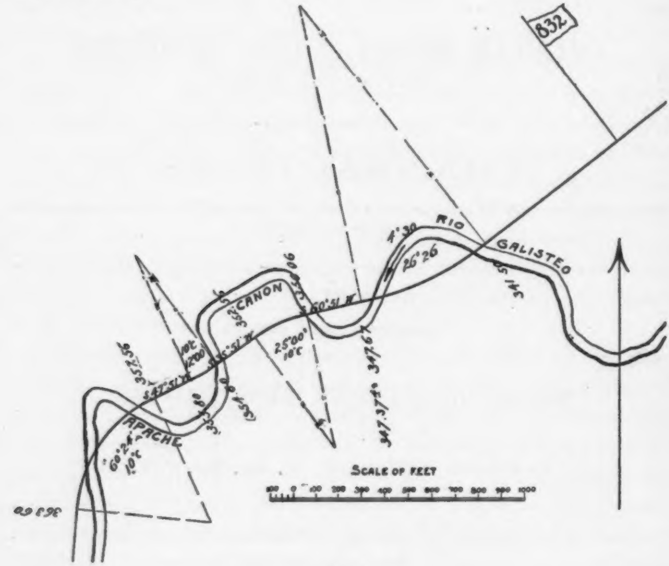


FIG. 1.

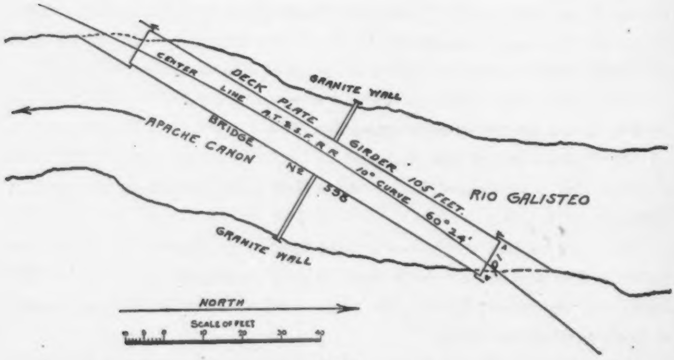


FIG. 3.

Fig. 5 is a cross-section of the cañon showing the east "arch," looking westward.

Fig. 6 is a photograph of the bridge looking eastward.

Possibly some of the members who were in the excursion party following the Denver Convention of 1886, will remember that they rose

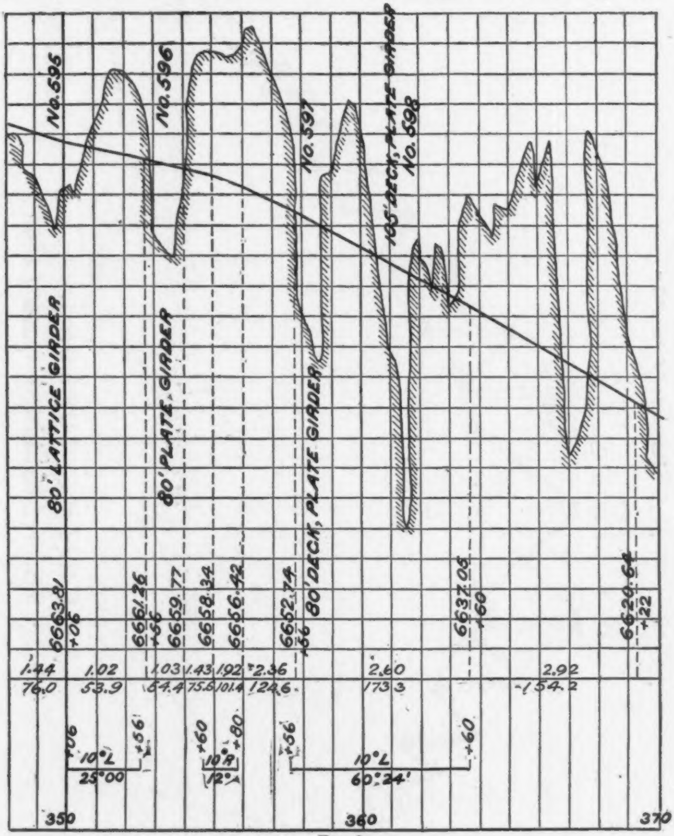
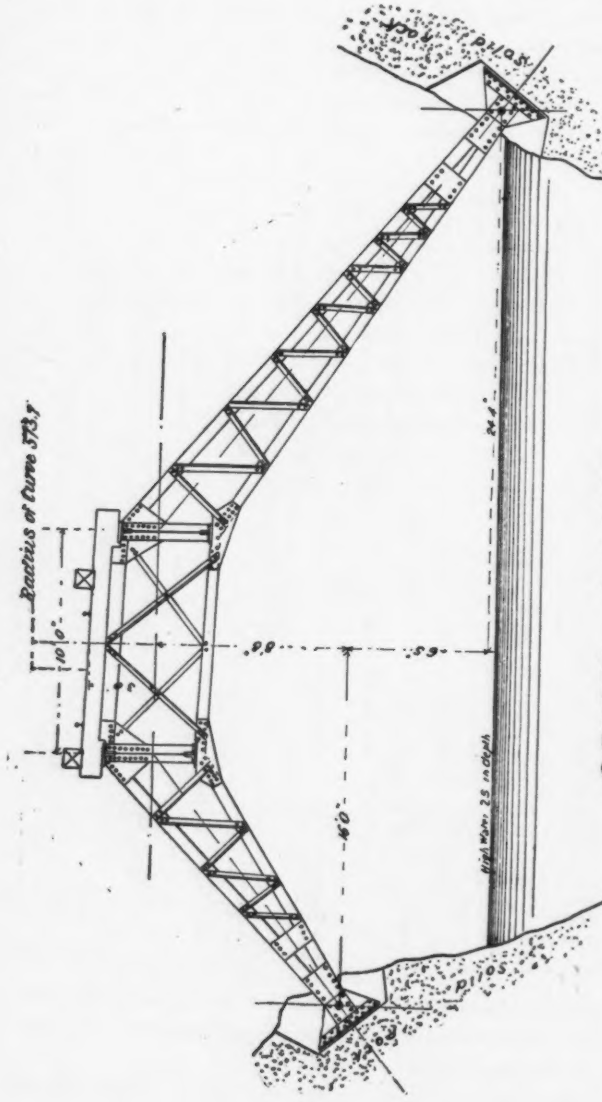


FIG. 2.

to their feet and waved their hats enthusiastically at this point. This railroad was built during the cañon war by the Santa Fé, but is now operated by the Rio Grande.

Fig. 6 shows the girders at the west end resting on an abutment;



CENTER SUPPORT.
Bridge 598, over Rio Galisteo. Apache Cañon.

FIG. 4.

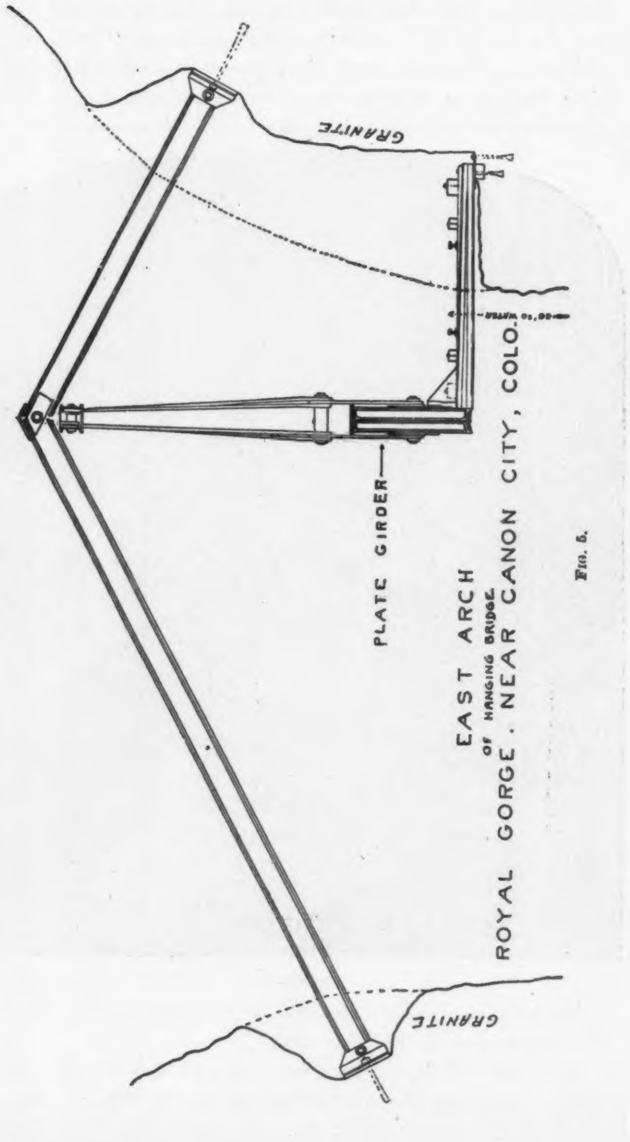

GRANITE
PLATE GIRDER
GRANITE
EAST ARCH
OF HANGING BRIDGE
ROYAL GORGE. NEAR CANON CITY, COLO.

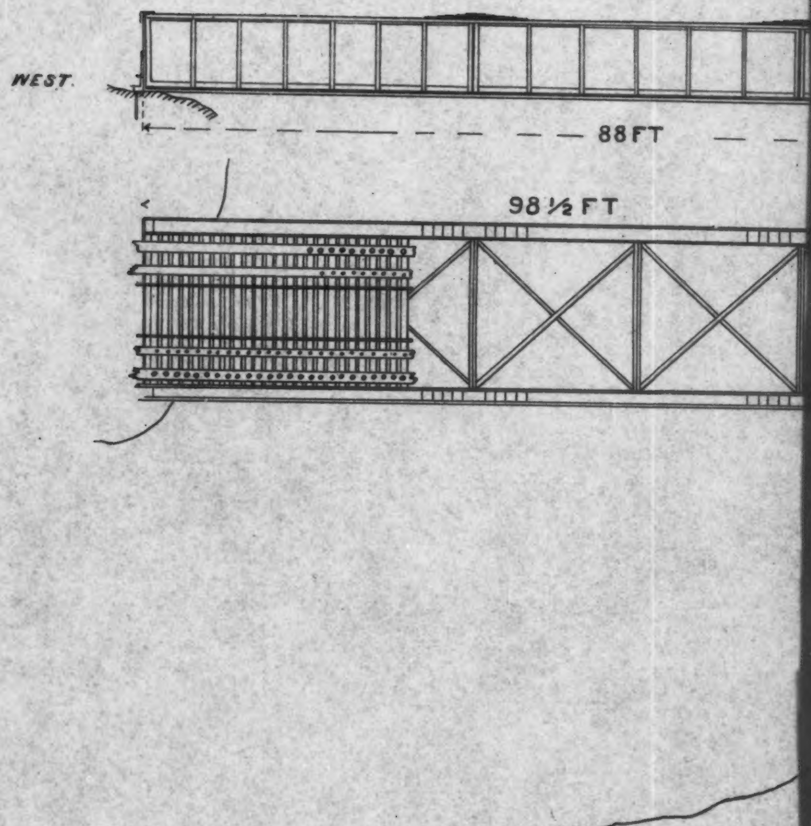
FIG. 5.

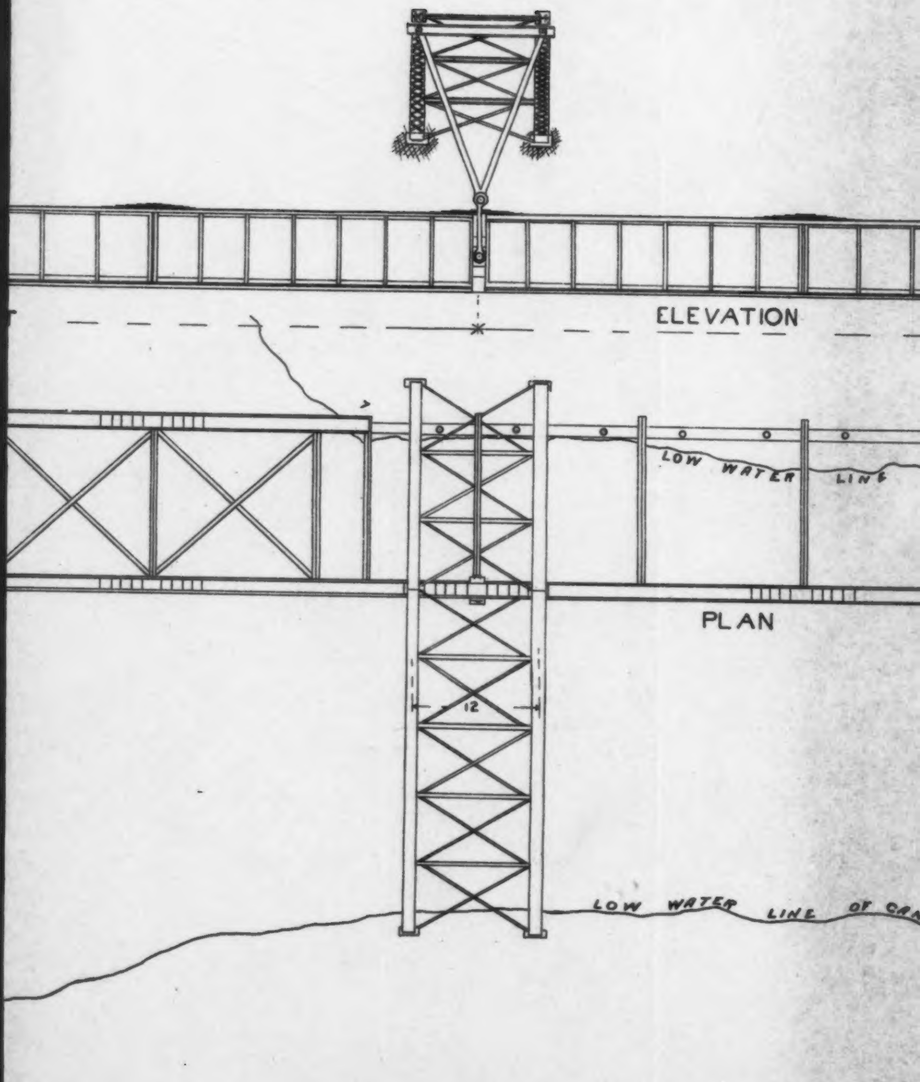
the crevice or side cañon entering the gorge from the north immediately east of the west end of the bridge; the termination of the north girder after crossing the side cañon; the arches that support the south ends of the floor beams, of which the north ends rest upon the granite wall of the cañon; and the telegraph "poles" above the arches on the left.

FIG. 6.

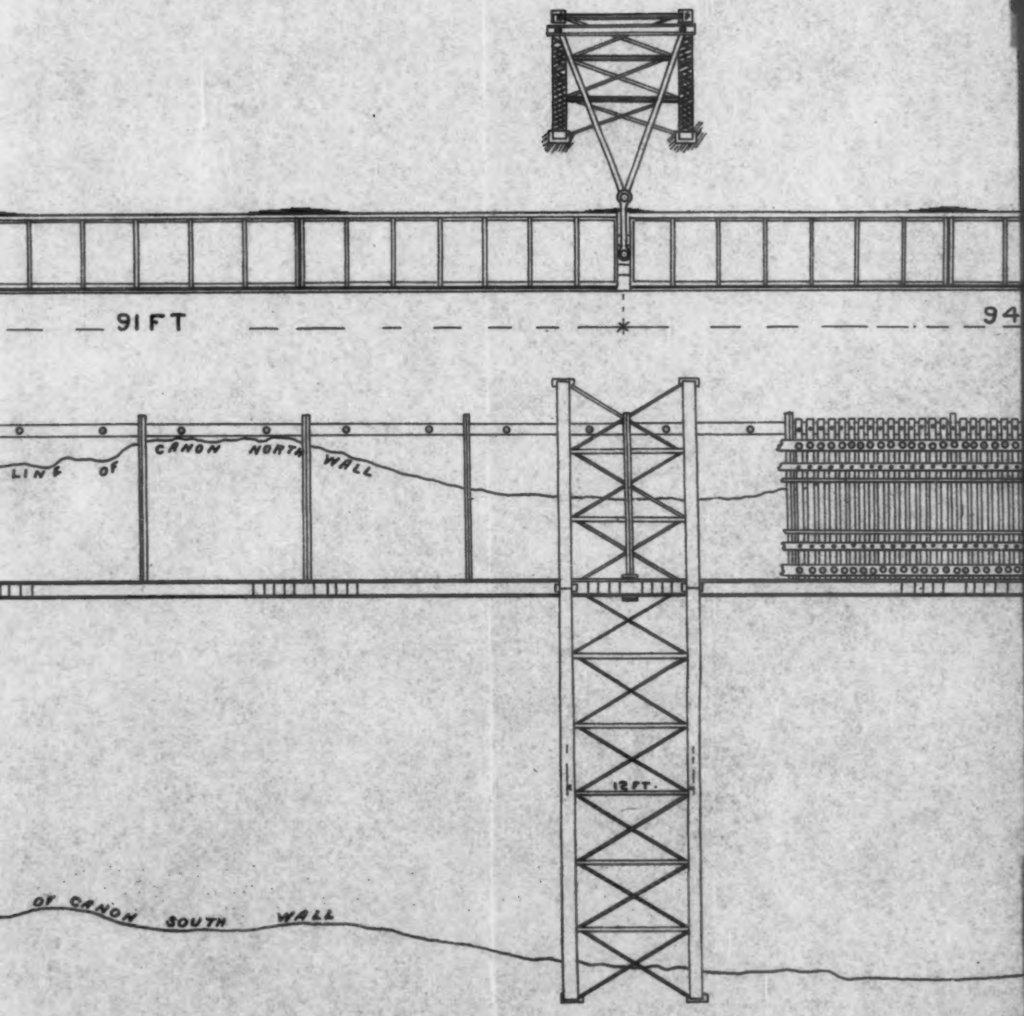
Plate LII is a plan and elevation of the bridge and its braces, and Fig. 7 shows how the bridge is hung.

Figs. 5 and 6 will give the reader some idea of the difficulty with which a transit line was first secured through the Grand Cañon. Men


WEST.
88 FT
98 ½ FT



ELEVATION
LOW WATER LINE
PLAN
12
LOW WATER LINE OF CR



91 FT
94
LINE OF CANON NORTH WALL
12 FT.
OF CANON SOUTH WALL

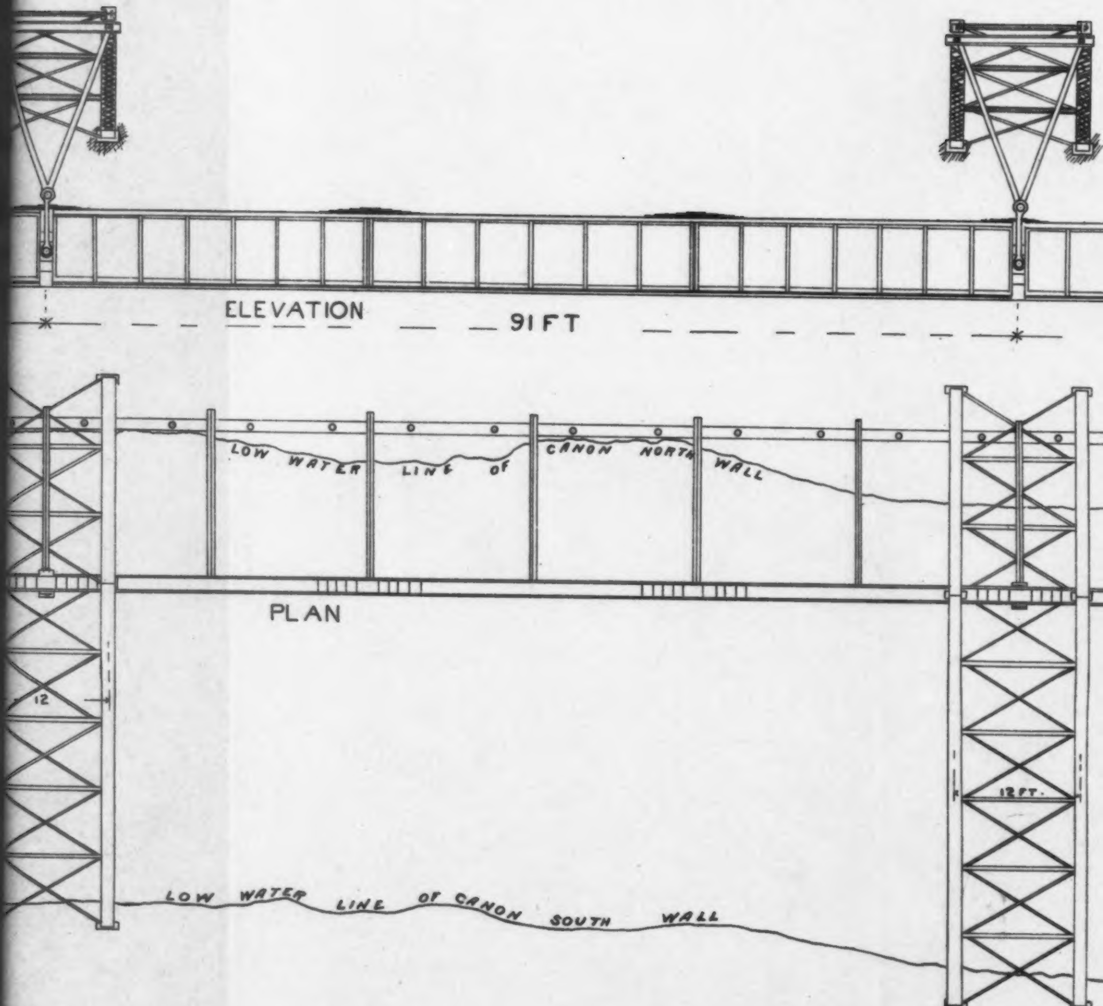

ELEVATION
91 FT
LOW WATER LINE OF CANON NORTH WALL
PLAN
12
12 FT.
LOW WATER LINE OF CANON SOUTH WALL

PLATE LII.
TRANS. AM. SOC. CIV. ENG'RS.
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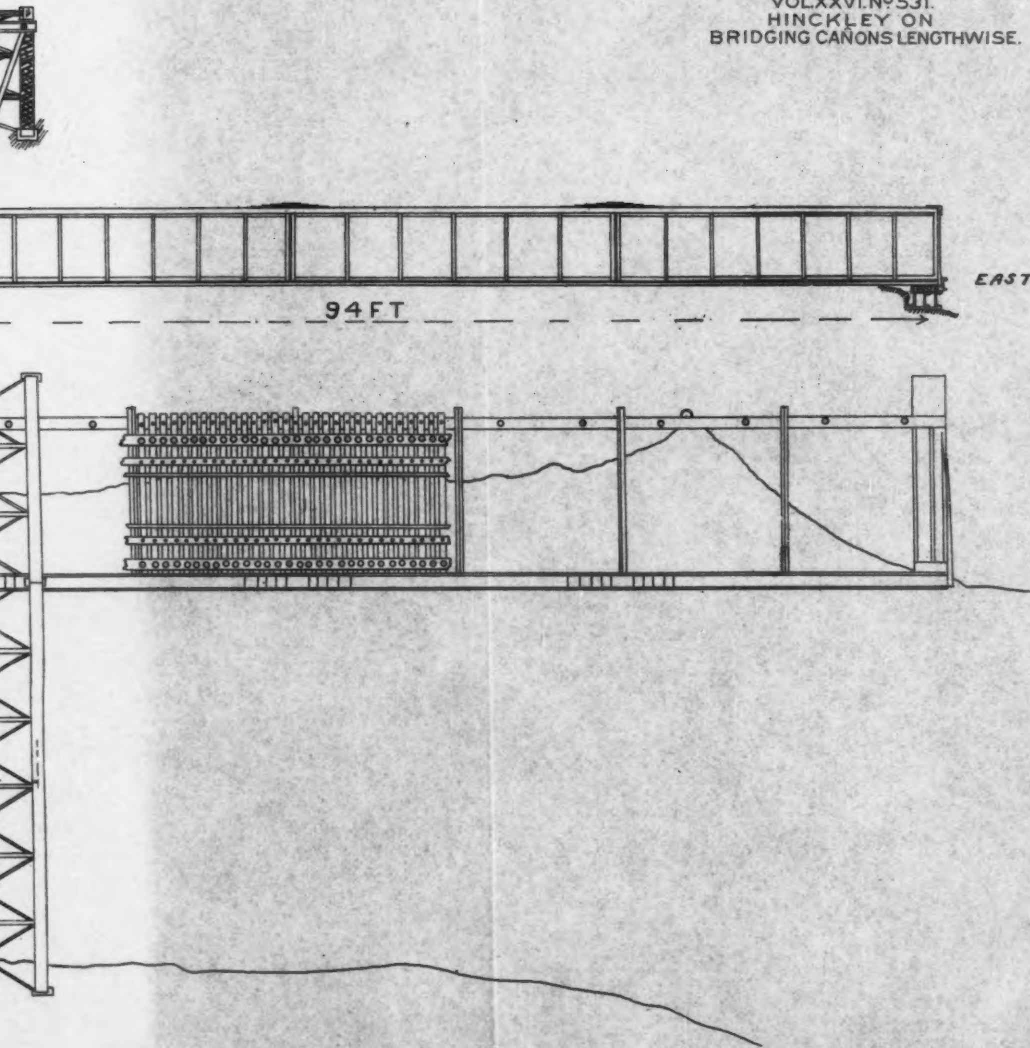
HINCKLEY ON
BRIDGING CAÑONS LENGTHWISE.



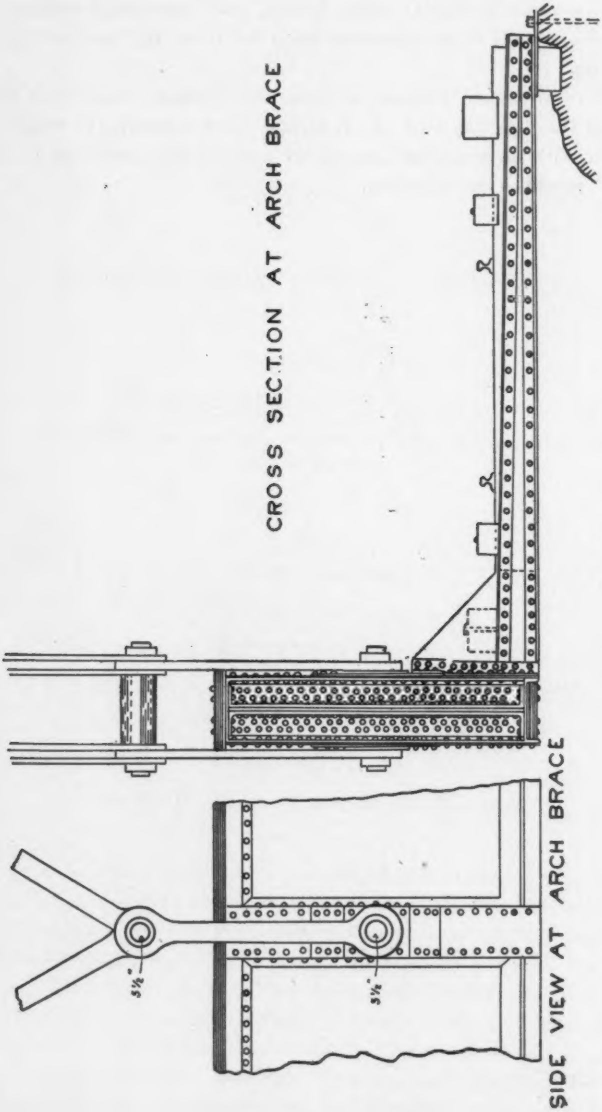


Fig. 7.

were lowered by ropes; mules, burros, cook stoves and transits all found the walls of the cañon too steep for them, and they went down stream.

The prominent features of these two bridges (which were built under the direction of A. A. Robinson, chief engineer) the writer has given, with the hope that some of our members may have some "oddities" to add to the collection.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

532.

(Vol. XXVI.—May, 1892.)

THE PHILADELPHIA TUNNEL OF THE BALTIMORE AND OHIO RAILROAD, ITS CONSTRUCTION AND COST.

By W. W. THAYER, Assoc. M. Am. Soc. C. E.

In November, 1885, the work was started of constructing the connection of the Baltimore and Ohio system with that of the Philadelphia and Reading. By this connection the Baltimore and Ohio Railroad Company established for itself a south-bound leader from the coal fields of Schuylkill, Carbon, Northumberland, Luzerne and other coal counties of Pennsylvania to the southern market, and opened for itself a through-line from the West to the North and East.

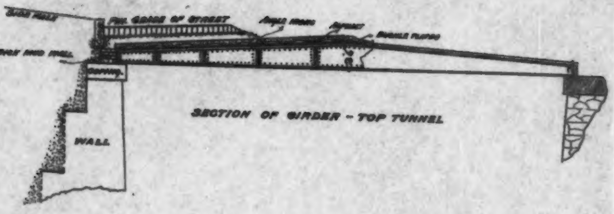
The tunnel problem was this: With an exceedingly low limit of head room, made necessary by the low elevation of the city grade of

the street system, and with a view to the retention of such grades as well as the care of the city reservoir, water supply and sewerage system, to rise from an elevation of 11.0 to that of the Philadelphia and Reading tracks (± 54.0) in a distance of 4 155 feet; and at the same time adopt a gradient which would have a sufficiently low limit of tractive force to be in keeping with the 8-degree curve required by the alignment. The character of the soil was, for the most part, of a shelving, seamy rock, hardening, at a depth of 10 or 12 feet, to a quartz, shelving transversely to the cut, and varying in firmness according to the location of its seam below the surface, at one point cropping out at the surface and again disappearing entirely and being replaced by soft clay.

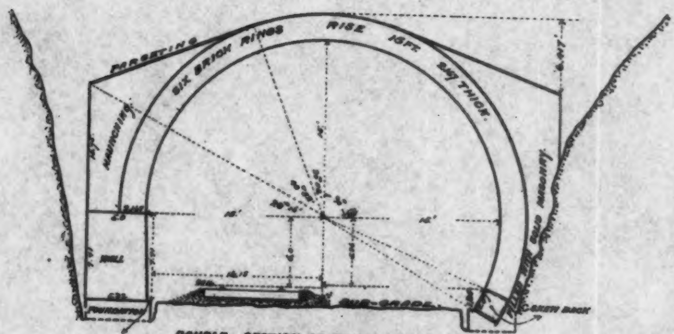
By reference to the partial sketch plan, Plate LIII, it will be seen that the alignment was as follows:

An 8-degree curve led up to the tunnel portal, joining there to a tangent 987 feet long; this ran to an 8-degree curve to the left with a length of 698 feet, and was followed by a tangent of 2 325 feet, to where a compound curve of 300 or 400 feet connected it with the Philadelphia and Reading Railroad tracks.

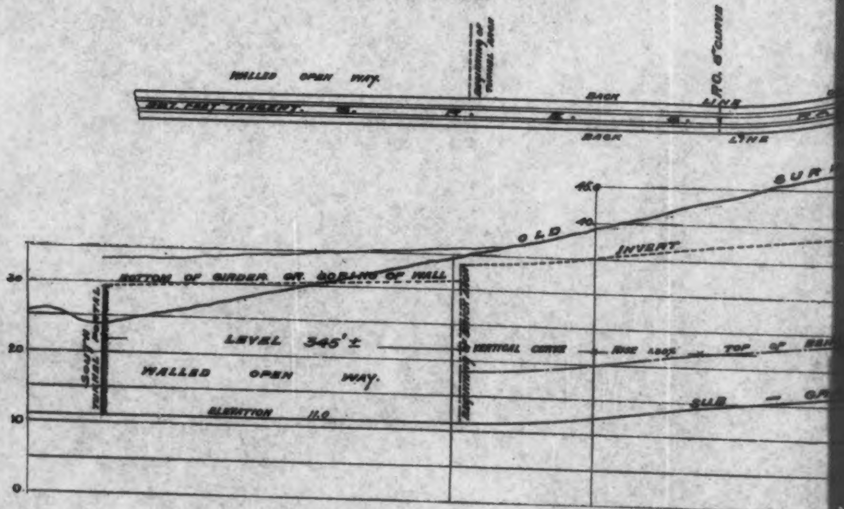
The section of the tunnel was varied according to circumstances. Where sufficient head room was available, the brick arch was used; but where the head room was insufficient to allow this, the girder-top tunnel was adopted. The original section of the tunnel arch, as approved and intended to be used, was a 15-foot half circle of brick, supported on a bench wall with its springing line 7 feet $8\frac{1}{4}$ inches above sub-grade; but where the rock showed good and full, a two-thirds circle of brick springing from a skew-back was used, the inside edge of which was $1\frac{85}{100}$ above sub-grade. By this two-thirds circle section, $2\frac{1}{2}$ feet of rock excavation was saved on the back, at a height of 7.71 above sub-grade, and all intervening spaces were filled in with solidly rammed concrete or masonry. (See section of brick arch.) The brick ring throughout was composed of six bricks, which, with their joints, made a thickness of ring of $2\frac{2}{10}$ feet. The bench walls were without coping and were, by plan, to be carried up 5 feet thick and straight; but this, too, was varied according to the character of the rock backing, in some cases all the interstices being made solid with masonry. From the top of the bench wall the haunching was carried up to a height of $6\frac{4}{10}$ feet below the elevation of top of the extrados of the arch at the

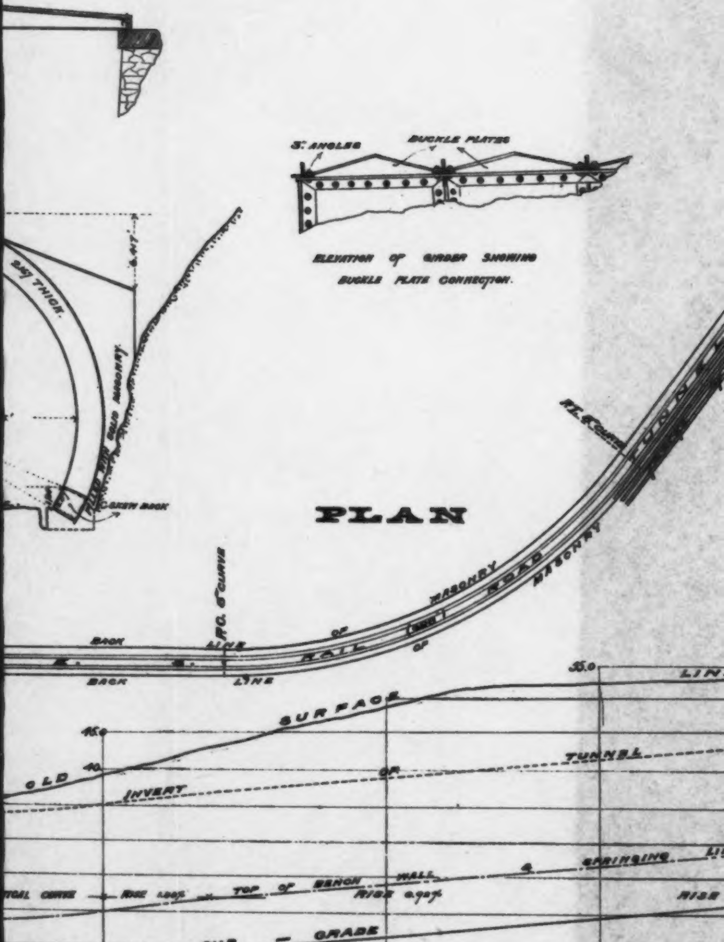


SECTION OF GIRDER – TOP TUNNEL



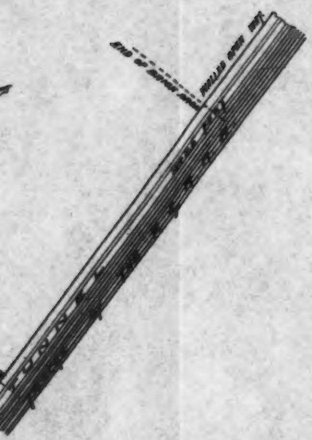
DOUBLE SECTION OF BRICK ARCH



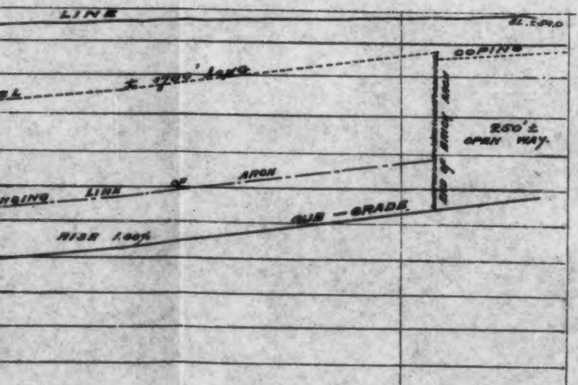


3" ANGLES
BUCKLE PLATES
ELEVATION OF GIRDER SHOWING
BUCKLE PLATE CONNECTION.
PLAN
MASONRY
ROAD
BACK
LINE
WALL
OF
SURFACE
OLD
INVERT
TUNNEL
SPRINGING
TOP OF BENCH WALL
SUB — GRADE

PLATE LIII.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XXVI. Nº 532.
THAYER ON
PHILADELPHIA TUNNEL.



PROFILE



center, and the space between this and the cutting was in most cases filled compactly with dry masonry.

Centers were struck not less than a week after the keying of arches, and accurate levels taken to show the depression, if any, of the crown. This depression or settling of the crown was found to average between three-fourths and one-eighth of an inch, except in one instance, where the centers were drawn before the haunching had been carried up to a sufficient height to prevent buckling. In this case the crown settled 2¼ inches. Here, the centers were replaced and tightly wedged, the arch unkeyed and the haunching finished. Observations showed the arch lifted to its correct position and only one-quarter-inch depression at the end of three weeks.

Where the girder-top tunnel was used, the walls varied from 6 to 11 feet in thickness at the bottom, according to their height, and had a batter of one-half inch to the foot on the face. In most cases where rock was found, the walls were filled out solid on the back to the rock cutting, letting original plan sections go, and making final measurements as the work progressed. The girder used on the iron-top tunnel was a single-web girder 2 feet high on the center and 1½ feet at the ends, with 3-inch top and bottom angle iron braces, with 3-inch stiffeners, giving a bearing on top for iron buckle plates $\frac{5}{16}$ of an inch thick and 2 feet square. Girders were laid 3 feet 2 inches from center to center, to which the plates were riveted, and angles were run over all joints and riveted to both girder and plates. On the top of these plates 4 inches of sheet asphaltum was laid, forming the bed for the block paving composing the finished street, a crown of $\frac{5}{10}$ of a foot being given for the sub-grade of the street.

An idea of the arrangement of the grades in the tunnel proper can be best understood by a glance at the annexed sketch profile. In the tunnel proper and open way were six changes of grade and two vertical curves, and all masonry was constructed on the true alignment, that is to say, vertical curves were carried through all walls, inverts and skew-backs in exact conformity with, and parallel to, the sub-grade.

From the south portal the iron covered way ran 345 feet; here the arch began, which ran 1 700 feet with frequent changes of section as before described, when, through lack of head room, the iron covered way was again adopted for a length of 250 feet. The remaining distance, 1 860 feet, was built as a walled cut or open tunnel until the

elevation of the Reading tracks was reached and the retaining walls ran themselves out on grade.

Length of south covered way	345.3
Length of brick arch	1 700.0
Length of north covered way	250.
Length of covered way	2 295.3, tunnel proper.
Length of open tunnel	1 860.
	4 155.3 feet.

The opening of such a trench in the heart of a large city, entailed the necessity of the care and maintenance of the water and gas supply and the sewerage system. A large 40-inch water supply main leading from the reservoir, was supplanted by extra pipes hung by girders across the cut until the making firm of the existing one was completed. Sewers were broken into and their contents conducted through trenches in the cut, pending the construction of new ones.

The writer submits the following final estimate of the completed work:

	Cubic yards.	
Earth and rock excavation	205 833.2	
Filling back of spandrels	66 278.4	
Rock filling	251.0	
Dry wall	281.4	
Bridge masonry, 1st class	100.2	
" " 2d "	5 455.	
Brick work	6 678.7	
Coping	647.1	
Concrete	156.0	
Rip-rap	142.0	
Rubble masonry	30 015.4	
Ballast laid	5 748.5	
Total cost		$429 564.77
Iron fence along coping of open tunnel		5 330.38
Re-throwing and laying Philadelphia and Reading tracks		4 867.85
		$439 763.00

This total of nearly $440 000 is the cost of the completed tunnel exclusive of cement, ties, rails, plumbing, sewer connection and iron-work of the covered way. The cement, which was the Improved Union brand, was supplied by the railroad company after careful tests, and under its inspectors was not stinted. The writer has endeavored to give above the accurate cost of this work irrespective of the attendant expenses incurred for damages by awards to properties, by loss of life or limb, or those expenses necessarily incurred in complying with city ordinances or records, and in the widening of streets and changes of grades consequent upon the undertaking.

The deaths during the work, as far as learned, were five, two of which were of spectators whose extreme carelessness was alone the cause of their deaths. Three employees were killed by falling derricks and slides of embankments.

Within one year from the starting of the work the rails were laid in the tunnel. During construction the work was pushed day and night, and in one instance the walls were put in before the center excavation was started, by trenching to the widths of the walls, filling the holes with masonry and dressing the front face. The blasting was at the same time carefully carried on without any detriment to the walls or their foundations.

Five years after construction, trouble was experienced by the gases of locomotives eating through the web of the iron girders, and greatly weakening the structure; but this has been corrected by throwing flat arches in between the girders, which completely protects the iron from rust and the detrimental influences of locomotive gases.

COST PER FOOT OF TUNNEL ONE-HALF CIRCLE-SECTION WITH BENCH-WALLS.

Two bench-walls	$23.60
Brick ring	32.40
Haunching	21.20
Parging	1.52
Foundations	2.25
Cost of masonry	$80.97
Excavation, 30 feet deep	39.73
Top filling	.80
Total cost of tunnel complete (1 lin. foot long).	$121.50

COST OF TWO-THIRD SECTION PER LINEAR FOOT.

Brick ring	$41.76
Backing	7.05
Foundations	2.25
Parging	1.52
Haunching	21.20
Skew-backs	5.50
Total cost of masonry	$79.28
Excavation, 30 feet deep	35.92
Top filling	.80
Cost per foot of two-third section	$116.00